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SEMATECH, A CASE STUDY:
ANALYSIS OF A GOVERNMENT-INDUSTRY
PARTNERSHIP

by

Robert M. Byron

September 1993

Thesis Co-Advisors: William R. Gates
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SEMATECH is funded through the Advanced Research Programs Agency (ARPA). Federal support of the semiconductor industry via the ARPA seems incompatible with Department of Defense interests. There are instances when federal support of R&D is justified. It seems doubtful that the semiconductor industry is one of those instances, but if it were, SEMATECH would not be the best way to channel government support.

This thesis shows that SEMATECH is not responsible for the turnaround of the semiconductor industry; that SEMATECH is not an appropriate model for government-industry partnerships; and that federal funding of SEMATECH should cease.

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SEMATECH, A CASE STUDY: ANALYSIS OF A GOVERNMENT-INDUSTRY PARTNERSHIP

by

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I. INTRODUCTION AND BACKGROUND

Critics proclaim the Semiconductor Manufacturing Technology Initiative, better known as SEMATECH, as the definitive future model of government-industry consortia. Many have argued that SEMATECH is responsible for the recovery of the U.S. semiconductor industry. However, SEMATECH is probably not responsible for the semiconductor industry's turnaround. It could not have had much effect because it initially focused on the commodity end of the semiconductor businesses, namely the production of basic memory chips, DRAMs and SRAMs (Dynamic and Static Random Access Memory). The initial emphasis in these areas made success unlikely because the United States gave up basic memory production to the Japanese. Attempting to recover the memory-chip market was impractical. In fact, the recent recovery in the United States is generally attributed to the proprietary microcomponents and application-specific integrated circuits (ASICs). Additionally, the timing wasn't quite right. The turnaround of the American semiconductor industry occurred coincidentally with the evolution of SEMATECH. The formation of SEMATECH had little influence or bearing on the recovery of an industry poised for a comeback after the disastrous 1980s. The semiconductor industry, nonetheless, had a major influence on the direction and strategy of SEMATECH.

A government-sponsored consortium is inherently unable to help industry get into profitable niches. This is due to two factors. First is the incentive problem.

Subsidizing business significantly diminishes incentives for change and innovation. Good analogies are the welfare and health care systems of this country. Second is the problem of direction. Proponents of SEMATECH claim it to be "hands-off" from government control. However, when it comes to strategy, the long arm of Uncle Sam still dictates that certain programs receive attention by earmarking where SEMATECH dollars are spent. SEMATECH fully follows these suggestions. They receive significant attention in SEMATECH's promotional literature, particularly in areas such as safety and the environment.

This thesis takes an in-depth look at SEMATECH and its effects on the semiconductor industry of the United States. It looks at SEMATECH as a consortium and determines that SEMATECH is not a model for future government-industry consortia. It discusses the effects of SEMATECH on semiconductor industry research and development (R&D). The thesis finds that federal support may not be necessary in this industry due to its profit potential and competitiveness. This thesis also examines the impact of SEMATECH on the semiconductor industry. It finds that not only does SEMATECH support selected U.S. semiconductor manufacturers, but it also supports those companies doing business with SEMATECH members through joint ventures. In the semiconductor business, technology transfer and spillovers of technology cannot be prevented. Through unavoidable spillovers, SEMATECH supports foreign chip makers. Finally, the thesis predicts the future of SEMATECH and its affiliation with the Department of Defense. In particular, it addresses whether

it is the government's or the defense department's responsibility to assure that certain industries remain within the borders of this country.

The conclusion of this thesis is that SEMATECH is not responsible for the U.S. semiconductor industry regaining market share; that SEMATECH is not a good model for future government-industry partnerships; and that federal funding of SEMATECH should cease.

A. BACKGROUND OF THE SEMICONDUCTOR INDUSTRY

The United States semiconductor industry has experienced significant changes throughout its 50-year history. Until the early 1980s, American companies were the undisputed leaders in virtually every field of the electronics industry, especially semiconductors.

By the early 1980s, the process of globalization had markedly transformed the semiconductor industry. Over one-third of the world's semiconductor output was sold across national borders. While Japanese firms claimed as much as 70 percent of the United States market for memory chips in 1981, American firms remained dominant in microprocessors and other logic devices. (Ziegler, 1992, pp. 160-163) During the middle 1980s, the Americans continued to lose significant market share for semiconductors to Japan. This was especially true in DRAMs and SRAMs.

DRAMs represented the backbone of the semiconductor industry because of their high-volume, low-defect, low-cost production. Although Americans pioneered DRAM technology (invented by Intel in 1971), American chip makers saw their

Worldwide Semiconductor Sales

1992 Total: $74.4 Billion

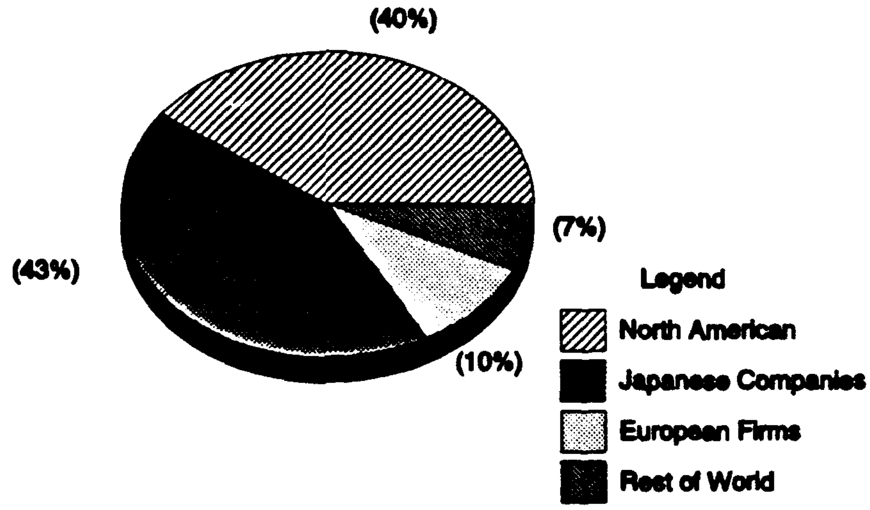

Figure 1: Annual nominal sales growth in 1992 was 17 percent.
SOURCE: *Standard and Poor's Industry Surveys*

market share in memory chips overtaken by the Japanese. High initial profit margins in the DRAM market lead to a worldwide glut in 1985. This caused prices to drop significantly. Many American firms left the DRAM market all together. At one point, there were only two United States suppliers, Texas Instruments and Micron Technology. IBM and AT&T also produced DRAMs, but for internal use only (they were "captive" producers). This caused a panic within the United States semiconductor industry. Many industry analysts attributed Japan's success to MITI's

(Japan's Ministry of International Trade and Industry) formation of the Very Large Scale Integration (VLSI) consortium. (Katz and Ordover, 1990)

Semiconductor companies moved away from the memory production business because the worldwide glut transformed these items into low-profit-margin commodity products. American companies instead focused on proprietary products and creating market niches because of their interest in the high-profit-margin products. Application-specific products now account for the largest portion of the United States semiconductor business (*Standard and Poor's Industry Surveys*, Jun 93).

Due to allegations of memory-chip dumping and intense lobbying efforts by the semiconductor industry, American legislators and trade representatives arranged the 1986 Trade Agreement with Japan to aid the chip producers. This five-year agreement imposed worldwide controls on Japanese-produced semiconductors. The American semiconductor industry perceived DRAMs as the key "technology driver" in semiconductor production. The result for the United States was predictably disastrous; DRAM shortages caused memory chip prices to skyrocket and Japanese firms earned windfall profits. The results for electronic industries requiring memory chips, including United States computer manufacturers and consumers, were equally disastrous. Because of its perceived "success" in protecting the United States semiconductor industry, the government extended the trade agreement for an additional five years in 1991. (Lindsey, Feb 92, p. 42)

The U.S. semiconductor industry has recovered its market share in the last two years. The industry gives most of the credit for this turnaround to the proprietary

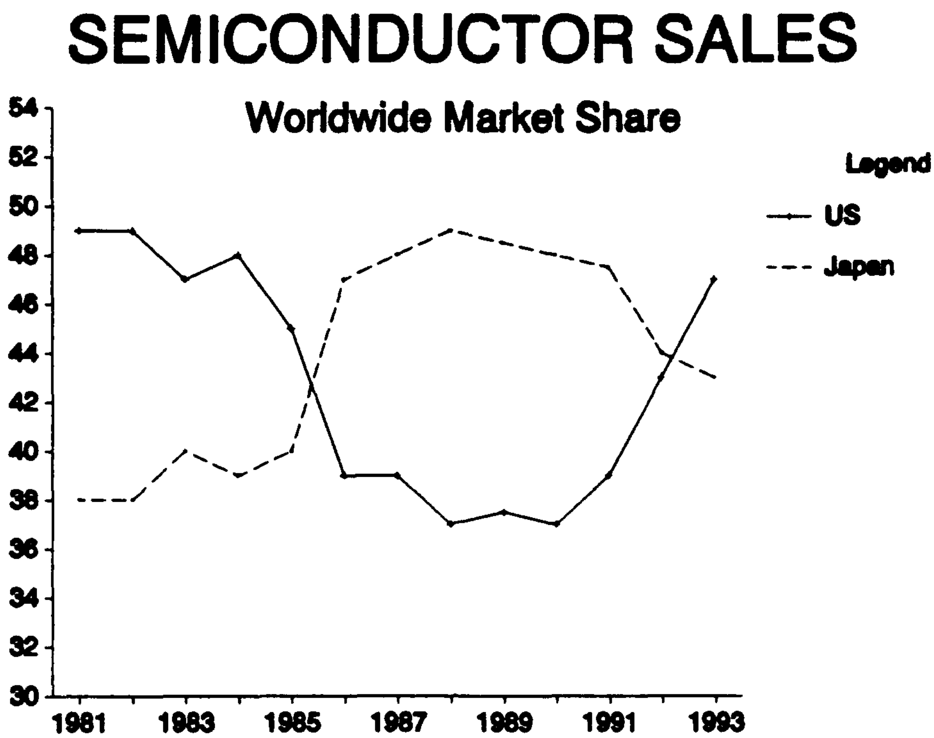

Figure 2: The latest report (July 1993) from VLSI Research, Inc., has Japan with 42.5 percent and the US with 47.5 percent share.
SOURCE: VLSI Research, taken from *SEMATECH Success*.

microcomponents (i.e. microprocessors) and application-specific integrated circuits (ASICs). These are products that depend more on innovation rather than the manufacturing process.

B. BACKGROUND OF CONSORTIA

To maintain United States international competitiveness, specifically with Japan, Congress passed the National Cooperative Research Act (NCRA) in 1984. This Act legalized R&D consortia, organizations in which competing members of the same

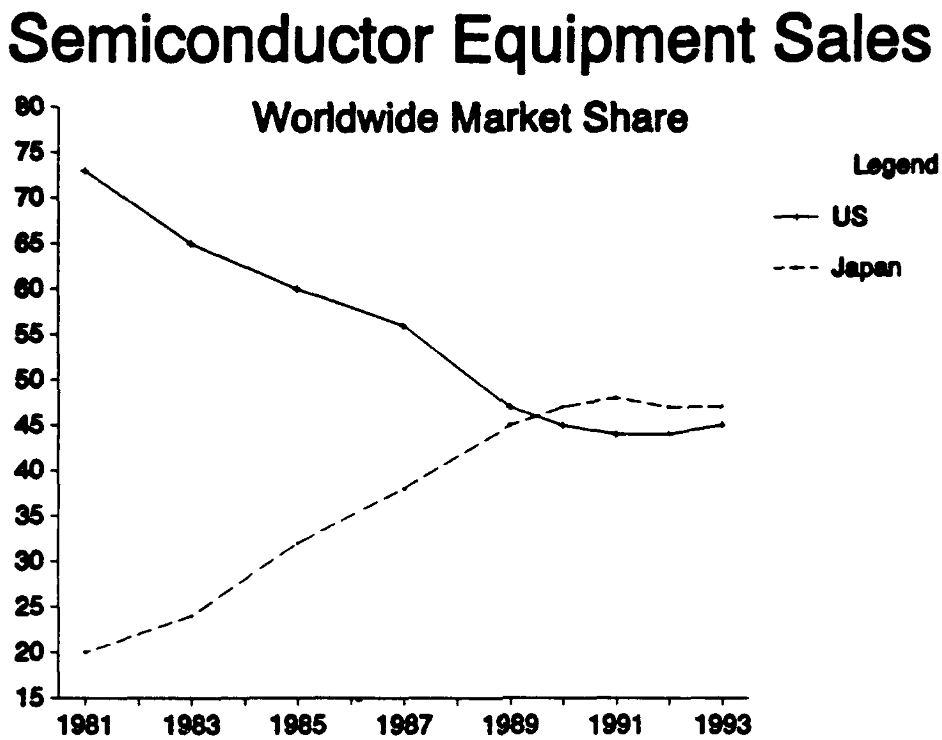

Figure 3: These percentages show how the trends of the early eighties have continued.
SOURCE: VLSI Research, taken from *SEMATECH Success*.

industry work together on pre-competitive research. Japan had encouraged collaborative R&D ventures since 1961, when it passed the Mining and Industrial Technological Research Association Law. This law legalized engineering research associations (ERAs). (Flamm, 1987) The high-technology industries, once dominated by American leadership, lost several market niches to the Japanese. International competitiveness and trade deficits with Japan, especially in the high-technology industries, concerned U.S. chip makers. Therefore, American firms convinced

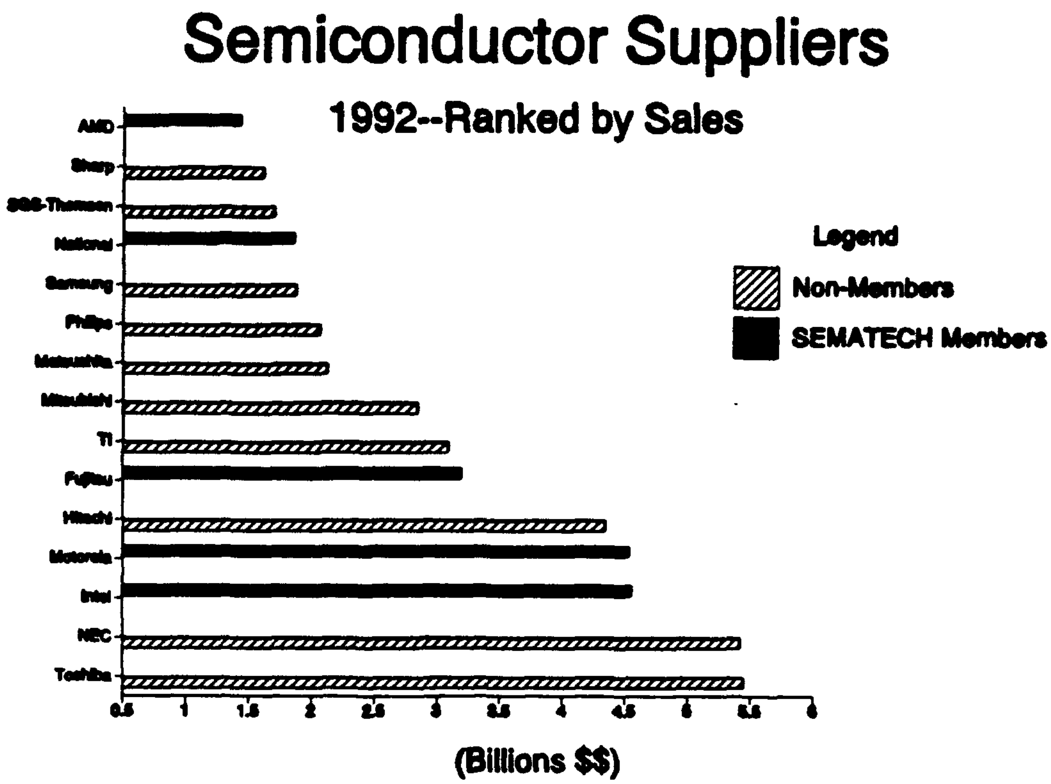

Figure 4: These do not include the captive producers IBM, HP and AT&T. Based on internal sales, IBM would rank fifth.

SOURCE: *Standard and Poor's Industry Surveys*.

Congress that they must be able to engage in the same type of ventures in order to compete.

Consortia were common in the United States in the banking and railroad industries until the Sherman Antitrust Act of 1890 made them illegal. The NCRA limits consortia in this country to R&D-related efforts. R&D consortia are different from joint ventures. R&D consortia members typically compete with one another in product markets while most joint venture participants do not. Comprised of

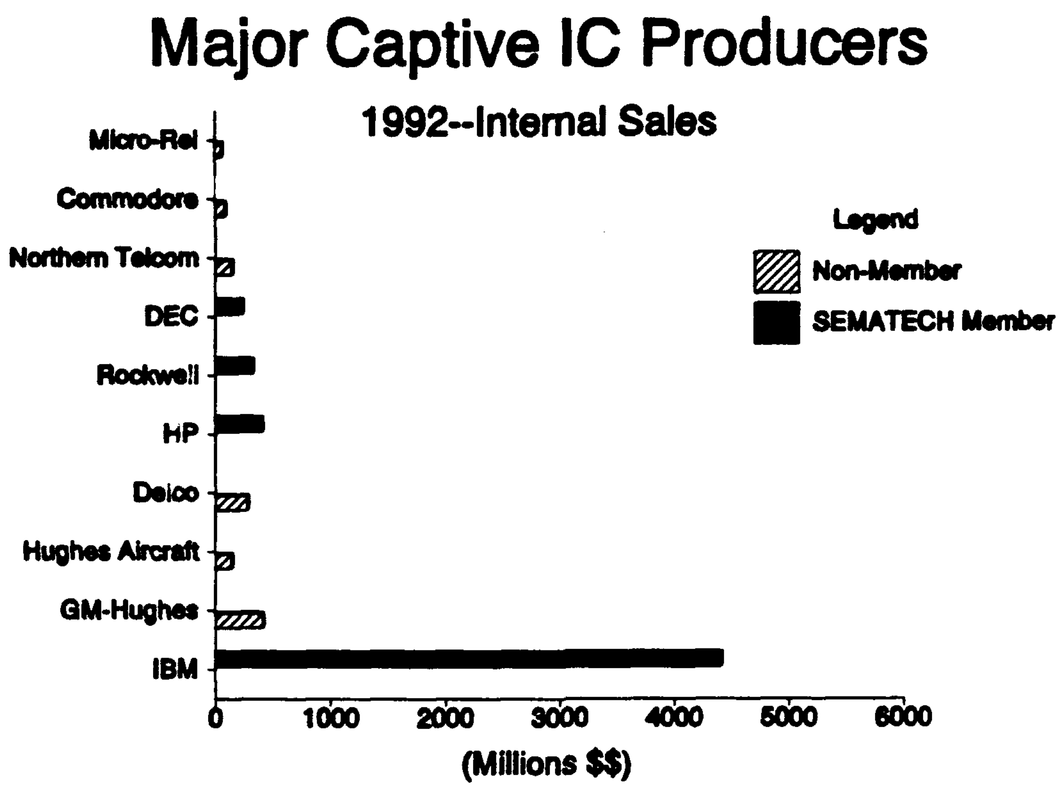

Figure 5: The number two through four companies are all subsidiaries of GM-Hughes.
SOURCE: *Standard and Poor's Industry Surveys*.

companies that manufacture similar products, R&D consortia are considered "horizontal" organizations. Joint ventures are typically "vertical" organizations. Each member produces a different component of the chain. Additionally: "... an R&D consortium tends to have a less focused goal because its potential output is uncertain and it is difficult to get members to agree on specific goals." (Evan and Olk, Spring 1990, p. 38)

1. Industry/University Cooperative Research Centers (IUCRCs)

Two other types of organizations distinguish themselves form R&D consortia. First is the Industry/University Cooperative Research Centers (IUCRCs). IUCRCs are similar to R&D consortia. An IUCRC brings companies together to fund a research project. Company representatives primarily determine the direction and conduct of the research and evaluate the center's progress. Universities normally initiate an IUCRC and receive government funding. In contrast, industry initiates and totally funds an R&D consortium.

2. Research and Development Limited Partnerships (RDLPs)

An RDLP is an agreement between general and limited partners. The general partner oversees the conduct of the research and receives the funding. The limited partners provide capital but have limited liability and no role in the partnership's management. RDLPs tend to focus more on later stages of innovation and have a short duration (two or three years). R&D consortia complement both IUCRCs, which conduct primarily basic research, and RDLPs, which undertake mostly commercial research. (Evan and Olk, Spring 1990) Also, R&D consortia involve the collaboration of competitors.

3. Types of R&D Consortia

R&D consortia can be divided into two main types by structure. The first is the freestanding body where research is conducted in-house. An example is the Microelectronic and Computer-Technology Corporation (MCC). The second type of

consortium serves as an administrative body that coordinates research either at universities or at member company sites, e.g., the Semiconductor Research Corporation (SRC).

4. Reasons for Joining Consortia

The principal reasons for joining a consortium are (1) to achieve economies of scale, (2) to share innovation risks, (3) to set standards for a new technology, (4) to share complementary knowledge, and (5) to help protect "leaky technology" from being appropriated by companies not sharing in the research efforts. (Gates, discussion with author) Companies view R&D consortium membership as risky because proprietary interests might inadvertently be compromised. There is also uncertainty over whether a company will be as successful as some of its competitors in exploiting R&D findings. Some potential member companies may believe the returns are not worth the effort. Because of such concerns, forming of this new type of R&D consortium involves risk. But R&D consortia are attractive because they potentially allow consortia members to leap ahead of or quickly catch up to foreign competition.

5. Consortia Criteria

William Evan and Paul Olk listed seven generic problems in organizing R&D consortia. Those problems are:

(1) Recruiting Personnel

(2) Obtaining Resources

(3) Recruiting New Members

(4) Making Decisions

(5) Resolving Legal Issues

(6) Understanding Membership Turnover

(7) Evaluating and Producing Products

a. Recruiting Personnel

Research consortia need especially qualified personnel. Employees are recruited from two general sources: member companies and outside sources. Sending its own employees to conduct research is the most effective way to transfer knowledge back to the member company. In addition, these employees help to represent their company's interests in the consortium. Also, using members' employees helps a consortium establish a competent staff quickly. On the negative side, a company with its own internal R&D program is not likely to send its top personnel. Therefore, the quality of personnel might be compromised.

b. Obtaining Resources

Consortia receive money and technical knowledge from member companies. Most consortia recognize that members have differing financial resources and degrees of interest in the consortium. Therefore, they permit varying levels of membership, targeting involvement to select projects, or other flexible membership options.

c. *Recruiting New Members*

Recruiting new members is necessary either to replace members who have left the consortium or to enable the consortium to grow. Generally, recruiting members does not depend on informing companies about the consortium's accomplishments. Instead, recruiting requires either convincing companies of the advantages of membership or expanding the scope of research to appeal to a broader audience.

d. *Making Decisions*

Because of the varying interests of consortium members, decision-making in this environment can be difficult. Most consortia have a board of directors with a voice in setting overall policies and direction, though the composition of those boards may vary. Some boards look like state representation in the House of Representatives; votes depend on the company's monetary commitment to the consortium. Alternatively, the board may look like state representation in the Senate, with each company having an equal vote. In addition to the board, there may be committees to oversee technical direction. The common thread among all consortia is that the decision-making processes elicit inputs from all members, but tend to favor those who have the most direct interests or a greater investment in the organization.

e. *Resolving Legal Issues*

The potential for antitrust violations and the need for regulatory approval for innovative products has made top consortium managers cognizant of the legal issues involved. NCRA does not completely exempt consortia from antitrust regulation. Consortia either have an in-house counsel or contract with a law firm to monitor its activities. These lawyers attend board meetings and may terminate discussions that, in their judgment, might inadvertently reveal trade secrets.

f. *Understanding Membership Turnover*

A consortium loses resources when a company departs the organization. There are two general reasons for terminating membership: disagreement over consortium operations or unrelated external factors. Disagreements may include dissatisfaction with the consortium's productivity, direction, or membership costs. Unrelated external factors could include a change of corporate strategy or management (e.g., a member company is acquired by a firm that does not want to continue membership).

g. *Evaluating and Producing Products*

Consortium managers emphasize that disseminating results to members is critical to maintaining good relations. Otherwise, individual members may fear they are not getting a fair return on their investment. Evidence of progress reduces members' concerns. This is best accomplished by producing tangible, money-making products or ideas from which member companies can benefit. For a

consortium to be successful, it must maintain active involvement by members to justify their inputs and to transfer technology back to the member. (Evan and Olk, Spring 1990, pp. 37-45)

C. BACKGROUND OF THREE CONSORTIA

This section describes three consortia for comparison.

1. VLSI

The Very Large Scale Integration (VLSI) consortium was formed in 1976 and disbanded in 1979. Many regard VLSI as one of the most successful Japanese cooperative ventures. It is discussed here because it was reported to be the Japanese model from which SEMATECH was formed.

> Japan's recent success in the semiconductor industry stems in large measure from a combination of government-backed loans and research subsidies, as well as a pooling of technical and scientific talent to promote efficient R&D. (Evan and Olk, Spring 1990, p. 38)

Sponsored by the Ministry of International Trade and Industry (MITI), VLSI was to develop advanced semiconductor technology to help Japanese firms compete effectively with fourth generation IBM computers. VLSI's membership included Fujitsu, NEC, Hitachi, Mitsubishi, and Toshiba. Each member assigned some of its research employees to the project. Researchers from MITI's Electro-Technical Laboratory (ETL) also participated. The VLSI Engineering Research Association was financed, like most ERAs, under the *hojokin* formula. The government provided 40 to 60 percent of the funds as interest-free conditional loans. These loans are repaid from profits derived from technology developed in the consortium. (Okimoto, 1984,

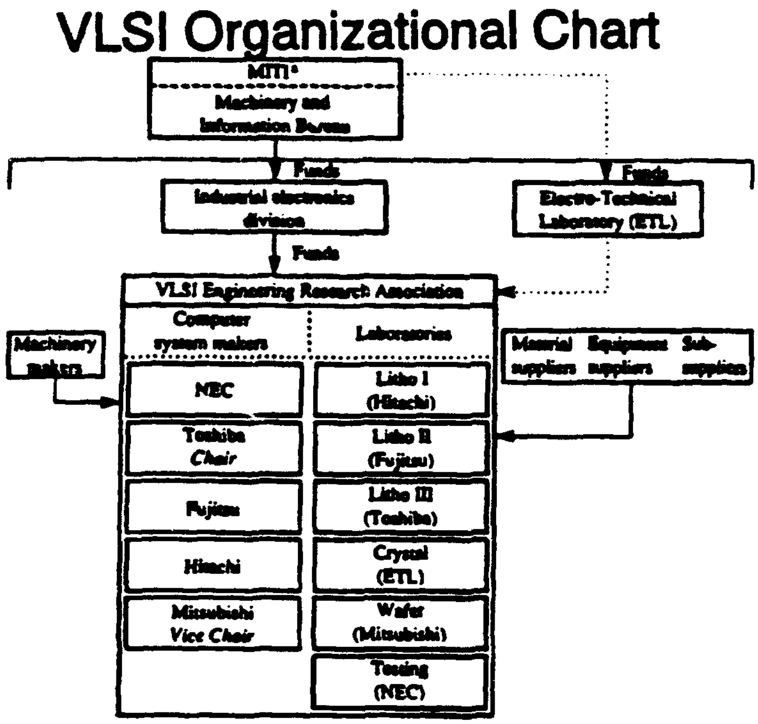

Figure 6: The basic breakdown of the VLSI Organization.
SOURCE: Katz, M.L. and J.A. Ordover, 174.

p. 78) The VLSI group was chartered with developing the generic technology for manufacturing random-access-memory (RAM) chips capable of storing 64K bytes of data. The VLSI consortium was a high-technology cooperative catch-up program. It was successful because it had a clear concise mission with a definitive objective.

> Its success in delivering the technology to manufacture 64K integrated circuits and in advancing Japanese capability in 256K technology can be attributed, to a large extent, to the clear-cut R&D tasks facing the consort'um members. This clear definition of tasks also implied that the R&D goals facing the firms supplying inputs to the device makers were clear, permitting better coordination along the vertical chain. Some...believe that the equipment and material suppliers who worked under contract with the device makers in the VLSI

consortium have been the main beneficiaries of the program. (Katz and Ordover, 1990, p. 176)

The VLSI consortium experienced significant start-up difficulties. Each participating firm feared losing proprietary knowledge that it possessed at the project's inception. Each firm was also engaged in separate collaborative R&D with other consortium' members. Some firms also had links to U.S. computer makers. (Flamm, 1987)

The organizational structure focused on close cooperation on pre-competitive research to ensure that participants benefitted from strong spillovers and technology transfers in generic areas. A spillover is an externality and benefit of R&D. Spillovers can be one of two types: competitive spillovers and technological spillovers. "Even with strong intellectual property protection, R&D investment by one firm may affect other firms through competition in the R&D market and in the product market." (Katz and Ordover, 1990, p. 150) Technological spillovers result primarily from private R&D investment and include patent protection. "Even though one firm may be said to have won the patent race, rival firms may benefit from the product or process that the winner has developed." (Katz and Ordover, 1990, p. 150)

In the VLSI project, most of the applied work was conducted in the private labs of the participating members, to ensure the propriety of new discoveries (although these patents were assigned to the Engineering Research Association in order to qualify for public subsidy). (Flamm, 1987) The traditional form of cooperation entailed only a limited interchange of research personnel and highly

controlled flows of information. Each cooperative laboratory was assigned a distinct research objective and was led by a representative from a different participating company; in other words, there was a "NEC" lab, a "Hitachi" lab, et cetera. As a result, only 16 percent of the patents generated by the VLSI consortium were filed jointly by researchers from different companies or by MITI. (Katz and Ordover, 1990, p. 178) Researchers returned to their firms once VLSI disbanded, ensuring maximum technology transfer to the participants.

One reason for VLSI's success is that many of the companies involved had participated in private joint-ventures prior to VLSI. They also anticipated future cooperation in joint ventures or consortia sponsored by MITI. Another important factor was the role MITI officials played in guiding the project from its inception. MITI coordinated VLSI from beginning to end.

> The fact that MITI could be expected to be involved in many research projects in which the VLSI-member companies would be participating created additional incentive for firms to act cooperatively with MITI and with each other. The expectation of future subsidies from the ministry together with the potential threat of exclusion from future projects and thus a loss of important R&D subsidies provided a countervailing force to whatever reluctance firms may have had in participating in joint research. The VLSI was not simply a cooperative venture among private firms--government money and incentives appear to have played an energizing role in its formation and ultimate success...(T)he visible success of the consortium in boosting the competitiveness of the Japanese signaled that closer collaboration in large scale consorti(a) is feasible without generating significant free-rider problems and uncontrolled spillovers of core proprietary information. Thus, the consortium has played a significant demonstration role for subsequent collaborative endeavors. (Katz and Ordover, 1990, p. 180)

The VLSI project is said to only have advanced the speed of R&D without producing many breakthroughs. Flamm also points out that the large number of patent

applications resulting from the VLSI association--more than 1000--as a measure of success, although it is not clear how many of those patents have commercial applications.

2. JESSI

Launched in 1989, the Joint European Sub-micron Silicon Initiative (JESSI) was set up in the European Community to ensure that European semiconductor companies gained access to leading-edge chip technology. The European governments have launched numerous past projects to enable Europe to compete more effectively with American and Japanese companies. These include: Eureka, Esprit, Prestel, Teletext, Informatique, Antiope, Airbus Industrie, Alvey, the Silicon Structures Project and several others. JESSI was a frantic effort by the European Community to secure independence from United States and Japanese semiconductor firms. Foreign firms accounted for over 90 percent of the European semiconductor market. (Blau, J., March-April 1992, p. 3) JESSI was designed with the belief that government needed to plan and subsidize the floundering semiconductor industry. (Gilder, 1989, p. 320)

The European Community pays between 40 and 60 percent of JESSI's budget. The budget was more than $400 million in 1992. (Lineback, J.R., 29 March 1993, p. 2) JESSI concentrates on "flagship" projects that include: high definition television (HDTV), digital audio broadcasting, digital cellular telephones, and advanced Integrated Services Digital Networks (ISDN). Smaller projects are grouped into wider-focused "clusters." They also have specific objectives, such as the 0.35

micron chip and the 64 mega-byte memory chip. To date, both specific projects are behind schedule. They are not expected to yield results until 1996.

Research at JESSI is conducted by the individual companies and is shared through licensing and patent agreements. JESSI is divided into four subprograms:

(1) memory technology projects in process development and manufacturing technology;

(2) basic and long-term research;

(3) equipment and materials; and

(4) applications.

Consortium officials admit that JESSI currently has too few projects in the computer field. They hope to correct this.

JESSI has eight member companies, but is dominated by three companies: Philips, SGS-Thomson, and Siemens. These large electronic firms report minuscule profits in the production of semiconductors, although Philips is the tenth largest semiconductor producer in the world, accounting for 3.1 percent of the world market. (Blau, April-March 1992, p. 4) JESSI does not allow foreign participation, although IBM-Europe is a member. Joint partnerships between member and non-member firms has been a touchy subject. One company, ICL plc of Great Britain, was expelled after being acquired by Fujitsu Corporation of Japan.

JESSI makes little use of the Continent's academic institutions, but hopes to increase their participation in the future. (Bernier, 19 Oct 1992, p. 4) According to John Blau of *Research-Technology Management*, JESSI's major problems are

directly related to Europe's fragmented semiconductor customer base, "which has saddled the national chip makers with low-volume production and high marketing costs." (Blau, March-April 1992, p. 4)

Although JESSI has not registered any significant accomplishments to date, it has managed to lower research costs and to pool European resources through the Semiconductor Equipment and Materials International (SEMI) organization. JESSI has been virtually ineffective to date, and its existence further entrenches the European semiconductor industry into a virtually hopeless "catch-up" situation with world producers, most notably the Japanese for memory chips and the United States for processors. T.J. Rogers, commenting on JESSI, stated:

> Amazingly, we still have "experts" who want us to emulate Europe's alphabet soup of technology consortiums such as JESSI, their equivalent of the U.S. chip consortium SEMATECH. JESSI showered billions on the European semiconductor industry. It also "rationalized" the industry by allocating certain market segments to various companies. Siemens became the DRAM company for Europe--and has since gone out of the business. Philips became the SRAM company for Europe--and has since gone out of that business...Today, there is no European chip industry or computer industry to speak of--thanks to the role of government programs like JESSI. (Rogers, 25 March 1993)

The industrial policies of Europe tend to favor less private enterprise and more government involvement, especially in key industries such as semiconductors.

3. SEMATECH

The Semiconductor Manufacturing Technology consortium (SEMATECH) was organized in 1987 as a U.S. response to a growing Japanese dominance of the worldwide markets for commodity chips (specifically DRAM, Dynamic Random Access Memory, and SRAM, Static Random Access Memory). Its mission, as of

January 1993, is "to create fundamental change in manufacturing technology and the domestic infrastructure to provide U.S. semiconductor companies the continuing capability to be world-class suppliers." (*SEMATECH Success, 1992 Annual Report*) SEMATECH is a Department of Defense/industry partnership consisting of the Advanced Research Projects Agency (ARPA, formally DARPA) and eleven of the largest U.S. semiconductor manufacturers.

a. SEMATECH Members

Member companies in the SEMATECH consortia include:

(1) Advanced Micro Devices, Incorporated

(2) American Telephone and Telegraph Company

(3) Digital Equipment Corporation

(4) Hewlett-Packard Company

(5) Intel Corporation

(6) IBM Corporation

(7) Motorola, Incorporated

(8) National Semiconductor Corporation

(9) NCR Corporation (owned by AT&T)

(10) Rockwell International Corporation

(11) Texas Instruments Incorporated

Three of the founding companies have left SEMATECH: Harris Corporation, Micron Technology Incorporated, and LSI Logic Corporation. Their departures resulted in serious public relations problems. These will be addressed later.

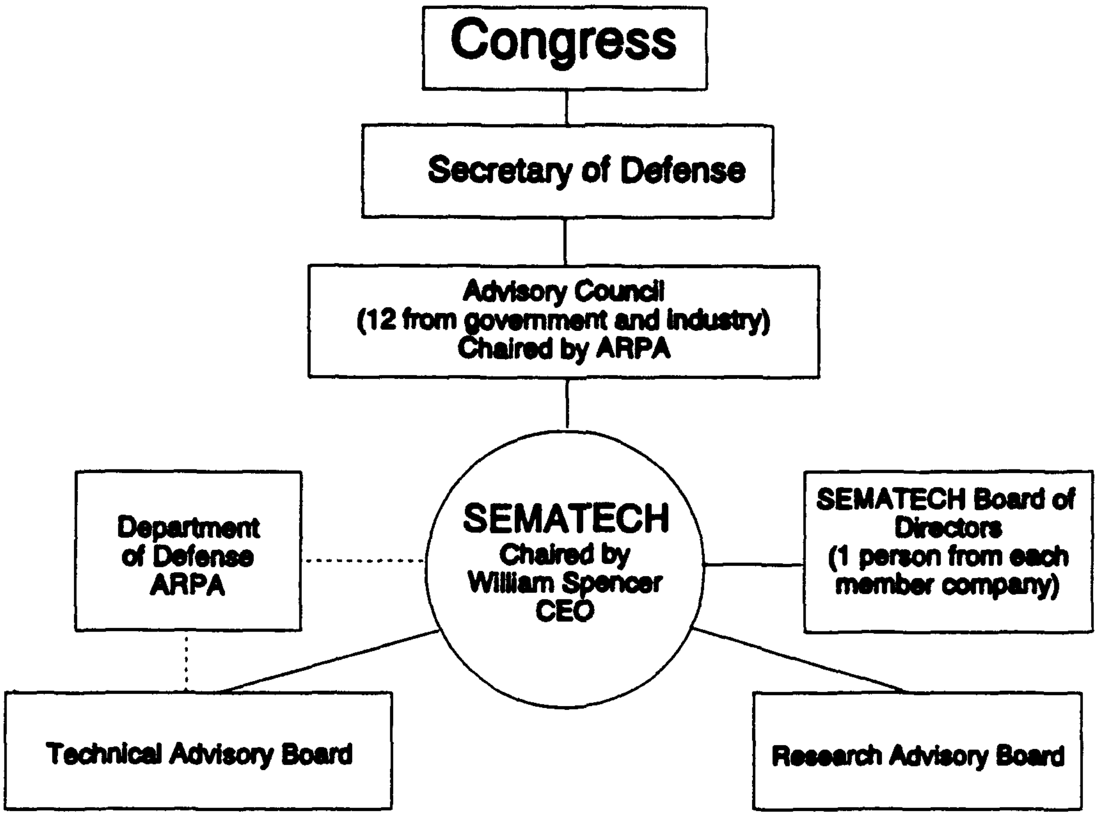

Figure 7: The SEMATECH Organization as it was originally envisioned. Robert Noyce was the founding CEO and ARPA was formally DARPA.
SOURCE: Katz and Ordover, 183.

b. Semi/SEMATECH

The consortium also has links with manufacturers of semiconductor materials and equipment through Semi/SEMATECH. Semi/SEMATECH was organized in 1987 as an independent chapter of the Semiconductor Equipment and Material International (Semi). Its membership is restricted to U.S. firms. This organization and the goals of SEMATECH reflect that it was formed to boost the supply sector. SEMATECH hoped for technological spillovers created by vertical relationships (vertical being the entire scope of the manufacturing process, from raw

materials to the finished product) among producers of basic semiconductor-manufacturing equipment and makers of semiconductors themselves.

c. *SEMATECH Funding*

SEMATECH is supported by public and private funds. SEMATECH's operating budget is $200 million per year. ARPA contributes approximately $100 million per year. Member firms collectively provide the other $100 million. Individual member-contributions range from a $1 million minimum to a $15 million maximum. More specifically, membership fees equal one percent of the member's annual semiconductor sales up to the $15 million maximum. (U.S. GAO, Jul 1992, p 17) In addition, each member must agree to join the Semiconductor Research Corporation (SRC). SRC's dues range from $65,000 to $2.4 million, depending on company size. There is also a one-time sign-up fee of $62,000. (Rice, 1 May 1988, p. 8)

Member companies contribute personnel to SEMATECH's research and administrative staff. The salaries and expenses for these personnel are deducted from the member company's annual dues. SEMATECH also employs close to two-hundred of its own personnel for research and support. This accounts for just over 50 percent of their work force.

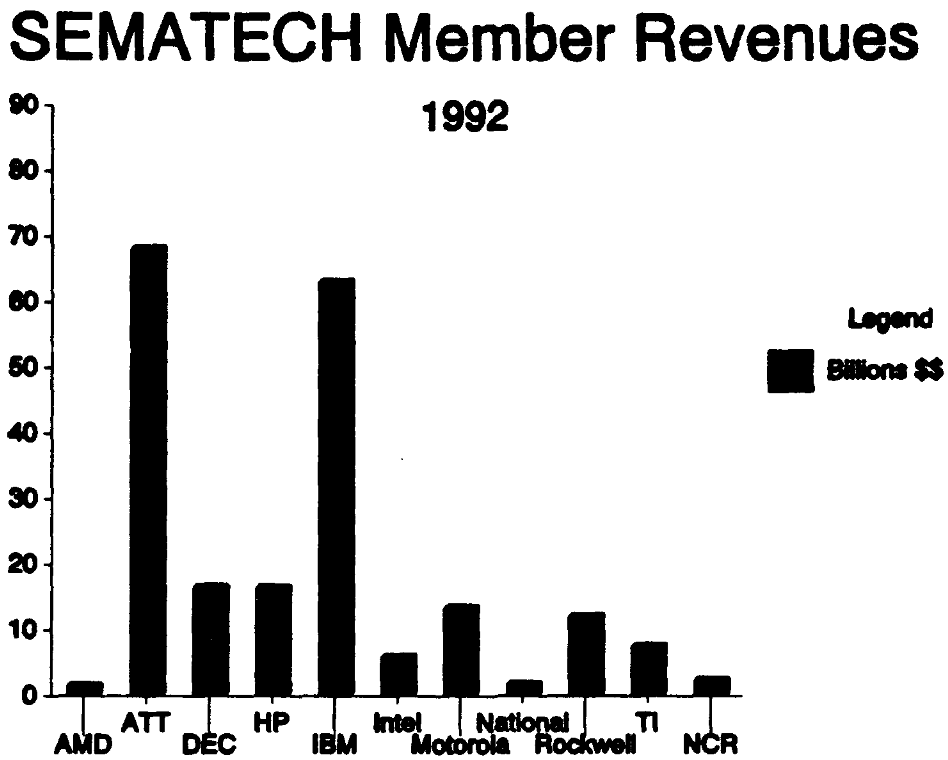

Figure 8: Each company has a minimum of $1.2 billion in revenues.
SOURCE: *Standard and Poor's Industry Surveys*.

d. SEMATECH Thrust Areas

SEMATECH's research focuses on "Thrust Areas." In other words, they channel funding into specific areas of interest. These include (*SEMATECH Success, 1992 Annual Report*):

- Contamination-Free Manufacturing
- Lithography
- Manufacturing Methods (Including Environmental Projects)
- Process Architecture and Characterization

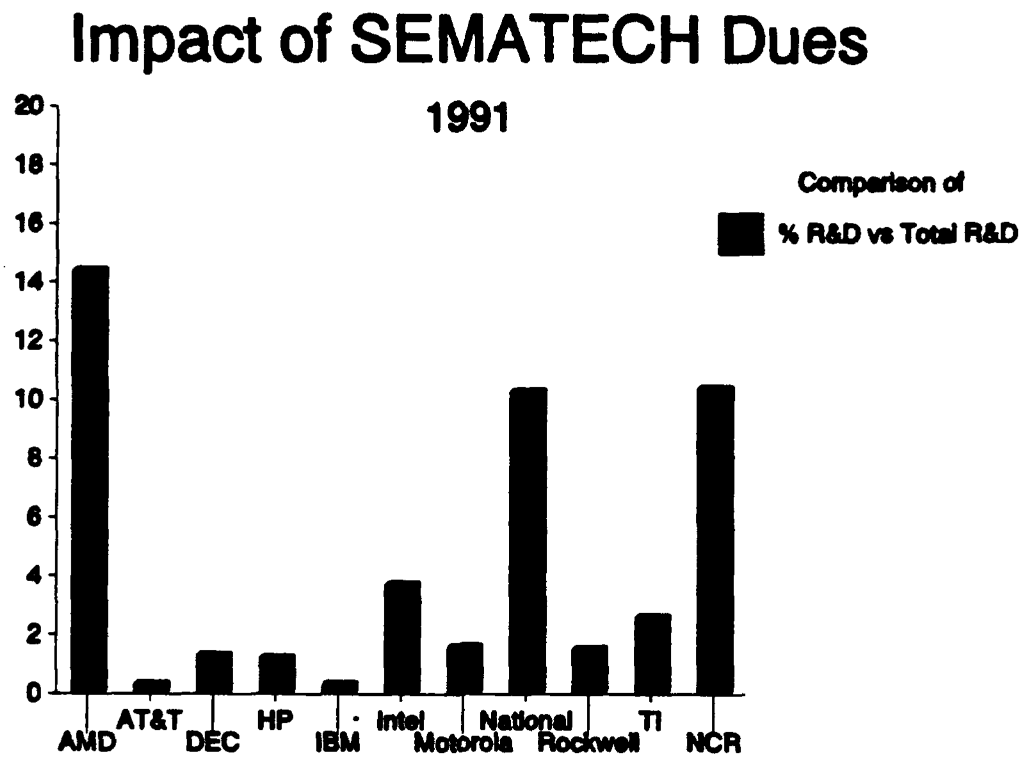

Figure 9: Based on $15 million dues divided by company's devoting 8.5 percent of total revenues for R&D.

SOURCE: Figures are taken from *Standard and Poor's Industry Surveys*.

- University and National Laboratories Programs
- Manufacturing Systems Development (CIM)
- Modeling and Strategic Integration
- Multilevel Metal and Etch
- Total Quality

SEMATECH believes that these thrust areas will have the greatest impact for producing the critical equipment and methods that its members require to regain world leadership in semiconductor manufacturing.

e. *SEMATECH Original Objectives*

SEMATECH originally established a five-year, three-phased program. SEMATECH members would achieve manufacturing parity with Japan upon the completion of phase two. They would reclaim world semiconductor manufacturing leadership by the end of 1992 upon the completion of phase three. Each phase called for smaller and smaller chip features on larger and larger wafers. Phase One, completed in 1989, developed integrated circuits with 0.8 micron features on 5-inch silicon wafers. Phase Two, completed in 1990, developed integrated circuits with 0.5 micron features on 6-inch silicon wafers. Phase Three, completed at the end of 1992, developed integrated circuits with 0.35 micron features on 8-inch silicon wafers. In addition, SEMATECH established eight main objectives in 1990. These objectives were developed after the "Three Phase" program, and are intended to incorporate both the "Thrust Areas" and a combination of technical aspects, the semiconductor infrastructure, and market penetration. Listed in *SEMATECH Success, 1992 Annual Report*, they included:

> **Objective 1**: Develop key process modules for member companies to integrate into proprietary process flows and products. Establish a baseline integrated process.
>
> **Objective 2**: Reduce member risk by delivering manufacturing processes and equipment modules for use in future equipment decisions.

Objective 3: Develop at least one qualified, viable U.S. supplier for each key equipment module and manufacturing system.

Objective 4: Develop long-term strategic alliances with selected suppliers to develop the required capability on the required time schedule.

Objective 5: Provide preferential availability of all funded equipment, systems, materials, supplies, and chemicals to the member companies.

Objective 6: Drive standards and specifications for open architecture, computer-integrated manufacturing systems, including a generic cell controller.

Objective 7: Continue to provide a forum for open communication. Ensure timely information transfer.

Objective 8: Establish collaborative centers of manufacturing science at selected universities and national laboratories.

These objectives have been met, though it appears they may not have been very ambitious. "SEMATECH was able to borrow technology from private companies and reproduce manufacturing results that other private companies had achieved years before--and do it with taxpayers' money." (Lindsey, p. 43) Specifically, SEMATECH purchased technology and equipment from IBM and AT&T to provide Manufacturing Demonstration Vehicles (64K SRAM and 4MB DRAM), for example, to build its semiconductor fabrication plant in Austin. The "fab" was built in 1988 to produce the 0.8-micron chips. (*SEMATECH Milestones*) These chips were already being produced by member companies as well as competitors.

f. SEMATECH's Current Mission

SEMATECH established a new mission for its 1993 to 1997 R&D program. The mission is to "create fundamental change in manufacturing technology and the domestic infrastructure to provide U.S. semiconductor companies with the

capability to be world-class suppliers." (*SEMATECH Success, 1992 Annual Report*) This mission will be measured by technology phases four and five. Phase Four's goal is to produce integrated circuits with 0.25 micron features on 8-inch wafers by the end of 1994. Phase Five's goal is to produce integrated circuits with 0.18 micron features on 10-inch wafers. To reach these goals, SEMATECH hopes to accomplish the following objectives (listed in *SEMATECH Success, 1992 Annual Report*):

> **Objective 1**: Provide unit processes and generic manufacturing methods for members to integrate into their proprietary process flows and products.
>
> **Objective 2**: Ensure that there is a viable supplier infrastructure capable of meeting the members' requirements for key equipment modules, materials, and manufacturing systems.
>
> **Objective 3**: Reduce sensitivity of cost to manufacturing volume.
>
> **Objective 4**: Provide programmable factory systems capable of responding to process changes with first-pass success.
>
> **Objective 5**: Cooperate with the Semiconductor Research Corporation, ARPA, and national laboratories to develop a research and educational infrastructure necessary to sustain U.S. leadership in semiconductor technology.
>
> **Objective 6**: Maintain open forums for effective communications, collaboration, and consensus building with the SEMATECH community.

According to GAO, ARPA believes that this plan has clearly stated technical objectives that are broken down into measurable criteria and linked to SEMATECH thrust areas. These objectives, like those written in 1990, all appear relatively subjective. Therefore, measuring their success depends more on opinion than fact.

g. *SEMATECH Accomplishments*

Since SEMATECH let its first contract in 1989, it has signed approximately 100 joint development and improvement contracts with equipment suppliers and member companies. SEMATECH has numerous accomplishments since its inception. In its own words, these include:

- the ability to construct cost-effective, world-class fabrication facilities capable of manufacturing 0.35 micron technology;
- generating 15 patents and 36 pending patent applications, helping enact more than 300 industry standards, participating in 110 equipment improvement and joint development projects and publishing more than 1,100 technical documents;
- providing a forum for communication within the semiconductor industry. By sharing pre-competitive data, SEMATECH claims to have shifted the industry's culture from a competitive, arms-length relationship between semiconductor manufacturers and their suppliers toward a culture that establishes long-term relationships between semiconductor manufacturers and their suppliers;
- improving strategic planning within the industry by developing a consensus among member companies on performance requirements and timing for next-generation equipment;
- developing common methods for evaluating, improving, and qualifying equipment and associated software;
- beginning to develop industry-wide standards for computer-integrated manufacturing (CIM) technology. (*SEMATECH Accomplishments*, Dec 1992, p. 38)

h. *SEMATECH and the Department of Defense*

The biggest selling points for the Silicon Valley lobbyists in getting SEMATECH funded were the decline of U.S. leadership in the semiconductor industry and the potential loss of American manufacturing capability in key areas, in

Worldwide Merchant Semiconductor Consumption (1992)

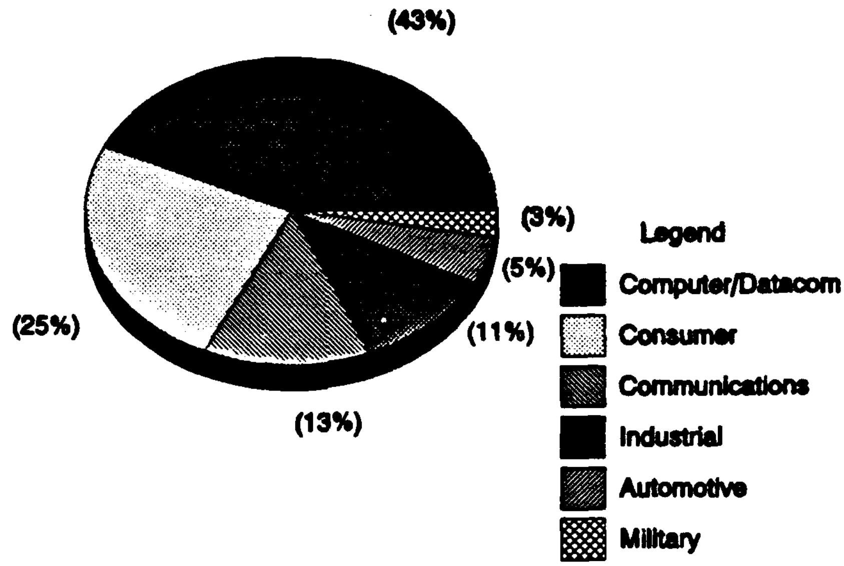

Figure 10: Note the percentage of consumption for the US military.
SOURCE: *Standard and Poor's Industry Surveys.*

other words, the decline of defense industries. To improve the defense industrial base and possibly acknowledge their funding source, SEMATECH has developed the ARPA/SEMATECH Synergy. In *SEMATECH Accomplishments*, SEMATECH makes the following assertions:

- that the Department of Defense must procure R&D to maintain U.S. technological superiority;
- that SEMATECH gives ARPA the ability to leverage industry dollars and expertise to ensure U.S. technological superiority in semiconductor manufacturing for critically needed defense electronics;

- that SEMATECH is a good investment: for every $1 SEMATECH uses to fund a project, the semiconductor manufacturing equipment and materials industry contributes $3 in total R&D spending.

These assertions are not substantiated. For SEMATECH to prove its "investment" assertion would be impressive if it were true. SEMATECH then goes on to show what influence each member company has on the defense industry (as if SEMATECH were responsible). It states:

> SEMATECH and the high-technology it supports are crucial to America's national security. SEMATECH is working to develop or improve several key semiconductor factory tools which in turn are used to make integrated circuits for advanced U.S. weapons systems. (*SEMATECH Success, 1992 Annual Report*, p. 12)

SEMATECH points out what weapons systems these integrated circuits support, leaving the reader thinking that SEMATECH is responsible for those weapon systems. *SEMATECH Accomplishments* lists "defense critical technologies" and details how many "electronic part types" various weapon systems include. Some examples of these are:

> **Microelectronic Circuits**: the production and development of ultrasmall integrated electronic devices for high-speed computers, sensitive receivers and auto control.
>
> **Software Engineering**: the general maintenance and enhancement of affordable and reliable software in a timely fashion.
>
> **High Performance Computing**: computing systems having 1000-fold improvement in computation capability and 100-fold improvement in communication capability by 1996.
>
> **Simulations and Modeling**: visualization of complex processes and the testing of concepts and designs without building physical replicas.

Electronic Component Part Types Per Weapon System:

Tomahawk Cruise Missile--1,270 Electronic Part Types

Abrams M1A Tank--2,500 Electronic Part Types

Apache Helicopter--4,600 Electronic Part Types

F-111 Bomber--8,900 Electronic Part Types

F/A-18 Hornet Attack Plane--14,400 Electronic Part Types

F-16 Fighter--17,000 Electronic Part Types

SEMATECH continues with vague breakdowns of many other weapon systems, highlighting the dependence on electronics. SEMATECH also lists the different defense-systems that member companies contribute, specifically Motorola, Intel, National Semiconductor, AMD, Rockwell, and Texas Instruments.

By discussing the crucial role of semiconductors in advanced defense uses, SEMATECH's *1992 Annual Report* leaves the casual reader with the impression that SEMATECH is responsible for the development of these semiconductors. But SEMATECH had nothing to do with their development. These weapons were developed long before SEMATECH even existed. In fact, these defense contributions were achieved by the SEMATECH-member companies themselves. These "accomplishments" appear more as simple statements defining areas of which most people are only vaguely familiar. To one familiar with this field few points of praise actually resemble any true SEMATECH accomplishments.

II. ANALYSIS AND EVIDENCE

This chapter evaluates SEMATECH as a consortium and as an organization. It compares SEMATECH to the Very Large Scale Integration (VLSI) consortium upon which SEMATECH was modeled. This chapter concludes by comparing SEMATECH to Europe's Joint European Sub-micron Silicon Initiative (JESSI).

A. SEMATECH AS A CONSORTIUM MODEL

SEMATECH has been hailed as the model for future government-industry consortia. This section evaluates SEMATECH as a consortium and as a government-industry model.

1. Evaluation of SEMATECH as a Consortium Model

Based on the definitions of Evan and Olk discussed earlier, SEMATECH is not a consortium. Rather, it is a conglomeration of an R&D Limited Partnership (RDLP), an Industry/University Cooperative Research Center (IUCRC), a joint venture, and a consortium. SEMATECH resembles a consortium because it involves horizontal companies. In other words, its membership consists of industry competitors with common interests in several product markets. However, a consortium is initiated and totally funded by industry. SEMATECH was initiated by industry with skillful Washington lobbying, but it is only half funded by industry. At the same time, SEMATECH funded Semi/SEMATECH (Semiconductor Equipment and Materials International), an organization that is comprised of 138 American

suppliers. [NOTE: The SEMI organization was in place before the formation of SEMATECH.] This exhibits the verticality of joint ventures. SEMATECH has established more than 51 Joint Development and Equipment Improvement Projects with more than 45 companies. (*SEMATECH Strategic Overview*, Dec 1991, p. 1-15) SEMATECH has also initiated the SEMATECH Centers of Excellence (SCOEs) and Participating Institutions. These are essentially research departments at more than 30 colleges and universities. They receive SEMATECH dollars for specific research projects giving SEMATECH the appearance of an IUCRC instead of a consortium. When the subject of funding is examined, SEMATECH looks more like an RDLP. Uncle Sam is the limited partner, providing over half of its total cumulative funding.

The following paragraphs will analyze SEMATECH as a consortium by detailing how SEMATECH management addresses the seven generic problems common to R&D consortia.

a. Recruiting Personnel

SEMATECH is comprised of research engineers and administrators "on loan" from member companies, in addition to its own internal work force. Each company handles its employees' tour with SEMATECH differently. Those people from each member company are typically on assignment to SEMATECH for two to three years, and serve in positions such as executive vice president of operations, division director, program director, project director, or individual contributor (on a project). Figure 11 shows a breakdown of member companies personnel contributions to SEMATECH. SEMATECH has hired approximately 160 additional personnel.

SEMATECH Employees

(1992 by Company)

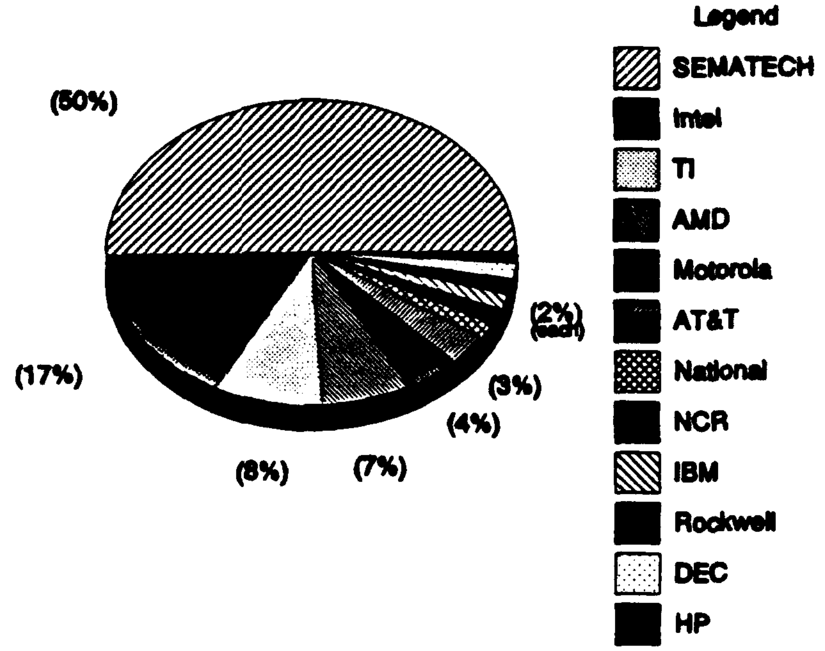

Figure 11: SEMATECH 1992 Employees by Company. Note that Intel employees outnumbered TI by more than two to one.

SOURCE: Cassell, J. and R. McCausland, 1.

The only way to effectively ensure thorough transfer of technology is through personnel working on and familiar with the specific project. Intel has about 50 percent more employees than Texas Instruments, which is the member company with the second largest number of employees in SEMATECH. This is attributed to Intel's emphasis on R&D and its strong support for SEMATECH. (Alcott) It is also interesting that member companies continue to pay the salaries of their own

employees. These payments are deducted from the member companies' dues. This means that member companies do not actually pay the salaries.

b. Obtaining Resources

Obtaining resources was discussed in the background of SEMATECH, specifically, the "SEMATECH Funding" section.

c. Recruiting New Members

SEMATECH has been unsuccessful in attracting new members. This is especially troublesome with the loss of Harris, Micron, and LSI Logic. Rockwell and IBM have also considered leaving the consortium. (Lineback and Dunn, 16 Nov 1992, p. 7) New members must not only pay the required dues for both SEMATECH and SRC, but they must also pay back dues, dating to the inception of SEMATECH. (U.S. GAO, Jul 1992, p. 17) This makes new membership cost-prohibitive even for the healthiest of companies. It also makes it less and less likely that new members will join because back dues will only cumulate.

> SEMATECH's membership policies discriminate against many of the companies that are leading America's comeback. SEMATECH's advertised dues of one percent of sales actually have a $1 million per year minimum. That means a $20 million company pays dues equal to 5 percent of its sales--perhaps all of its profits and five times the dues for a company with revenues of more than $100 million. What's more, SEMATECH's dues top out at $15 million per year, which means that companies with sales of more than $1.5 billion receive a dues discount. Thus, a SEMATECH member with $3 billion in sales pays dues equal to one-half of one percent of its sales--or one-tenth the rate of a $20 million company. SEMATECH's dues structure deliberately discriminates against America's small semiconductor entrepreneurs. (Rogers, 23 Jul 1991)

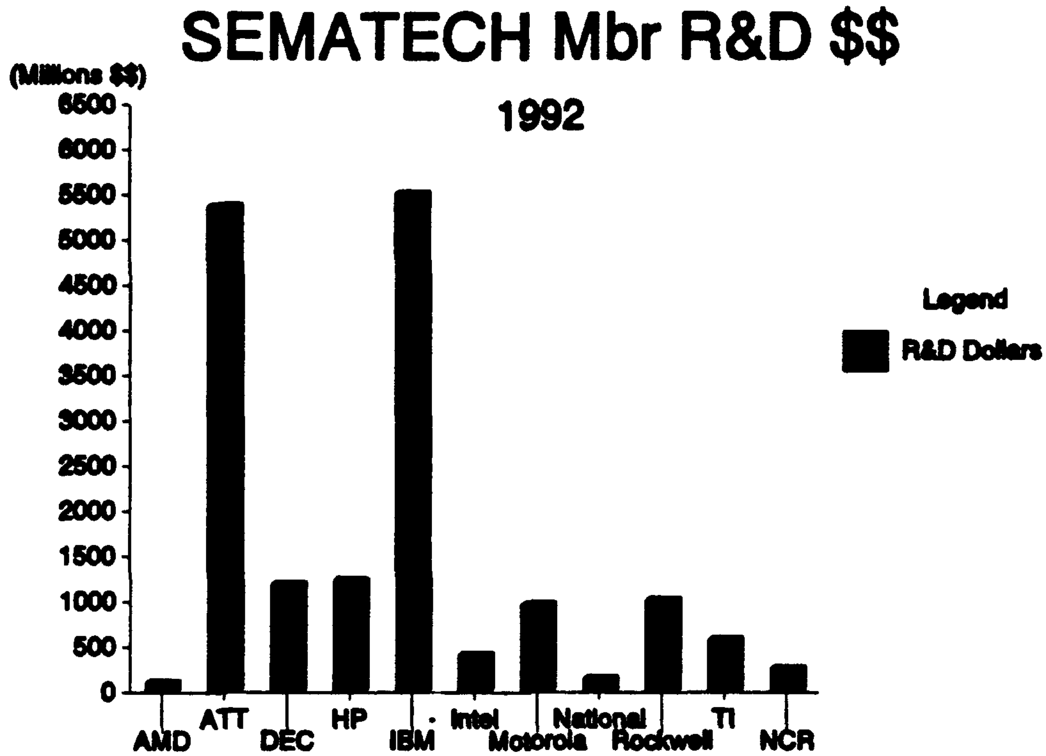

Figure 12: These amounts are determined by assuming 8.5 percent of revenues are invested in R&D.

SOURCE: *Standard and Poor's Industry Surveys*.

All of SEMATECH's current members have annual revenues of greater than $1 billion. Membership is the most troubling indicator that SEMATECH is not popular among semiconductor manufacturers. SEMATECH Communications manager Michele Higdon stated that SEMATECH member companies do not desire new membership. She said that SEMATECH is convinced that the current members best determine the R&D needs and requirements for the entire semiconductor industry. (Higdon, 15 Jul 1993)

d. Decision-making

Decision-making at SEMATECH is broken into four main areas:

(1) Board of Directors. The governing body, comprised of member company representatives, sets the mission, high level objectives, and strategy. Each member company has one seat on this board and it is typically chaired by a company CEO or a very senior executive.

(2) Executive Technical Advisory Board. The team of member company executives that provides continuing advice on the technology strategy and program selection. These personnel are assigned on a permanent basis and are typically "technology transfer" experts.

(3) Focused Advisory Boards. The member company managers that provide technical advice within a focused technical regime such as "Furnace and Implant" or "Multi Level Metal and Etch."

(4) Project Advisory Boards. The member company user representatives that provide specific project needs and project feedback. (Pankratz, 19 May 1993)

Decisions are made on an equitable basis, one vote per member, with the Board of Directors and the Executive Technical Advisory Board. On the Focused Advisory Boards and the Project Advisory Boards, a member company's voting weight is based on its annual dues. From a practical side, the more employees

that have a member-company allegiance, the more decisions that will be made in the parent company's favor.

e. Legal Issues

SEMATECH employs its own attorneys and hires law firms to litigate specific cases. All patent applications, patent infringement cases, and other legal issues are handled by these lawyers.

f. Reason for Membership Turnover

Harris Corporation, the latest company to leave SEMATECH, said the "company's needs weren't aligned with SEMATECH's research priorities." ("Harris Leaves SEMATECH," 6 Jan 1993, p. 3C) Harris' biggest customer is DoD. DoD requires rugged semiconductor devices in its weapon systems. These devices do not typify the newest in semiconductor technology. Rather, these devices are proven, effective, and reliable semiconductors used in military systems. Harris is more interested in Total Productive Maintenance (TPM) and improving manufacturing methods. Harris could not persuade SEMATECH to implement a TPM program. Harris left the consortium because it desired to put its SEMATECH dues into its own internal TPM program. (Blanc, 18 Jul 1993)

LSI Logic was the first member company to defect. Its departure coincided with an in-company restructuring. LSI's Director of Technology Transfer, David Sanders, stated that his company had different objectives than SEMATECH and that LSI was headed in another direction. He did, however, highly praise

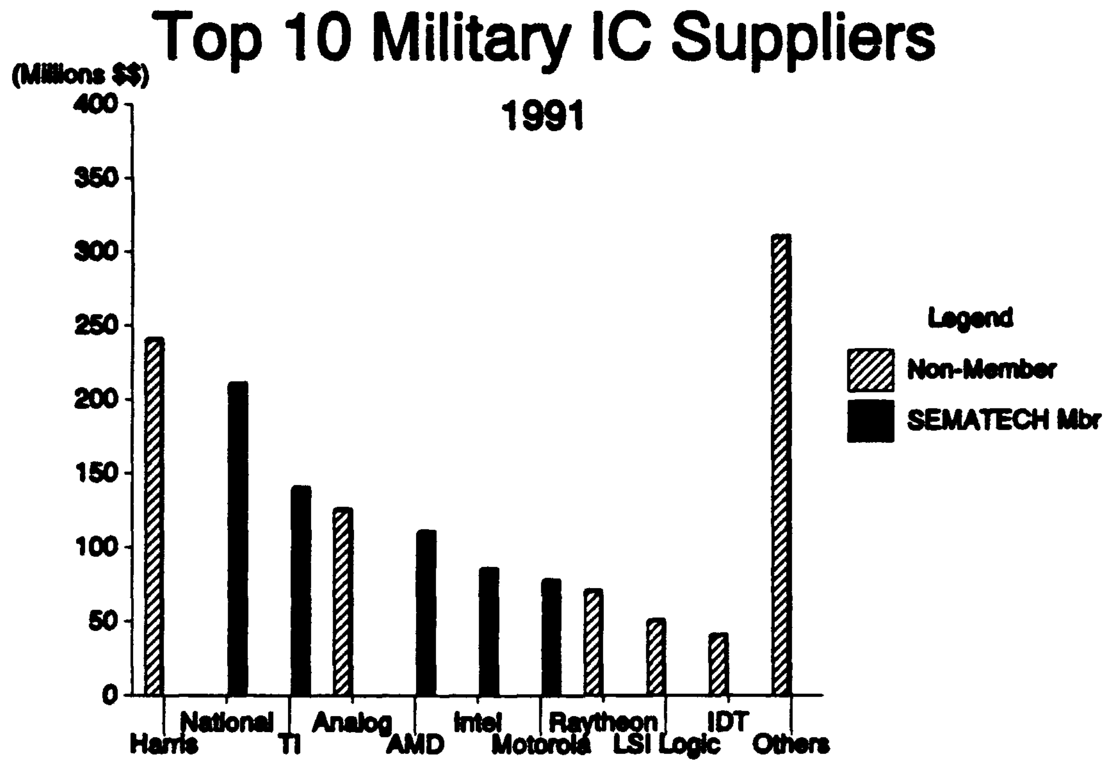

Figure 13: This shows Harris, a former SEMATECH member, as the leading military semiconductor producer.

SOURCE: US GAO, *Federal Research, SEMATECH's Technological Progress and Proposed R&D Program*.

SEMATECH and felt that it was a worthwhile and successful endeavor, just not for his company. (Sanders, 13 April 1993) Micron cited similar reasons for its departure. [NOTE: Micron and LSI Logic were the little guys in the consortium, both with revenues around $500 million.] Three reasons for termination are apparent with these three companies: dissatisfaction with the direction of the consortium, high price of membership, and changes of corporate strategies. Membership turnover does not exist at SEMATECH, only membership exodus.

g. Evaluating and Producing Products

Because SEMATECH emphasizes pre-competitive research, it does not produce commercial products. It does have production capabilities in its Austin, Texas plant. These facilities, however, are used to evaluate production processes, not to produce actual semiconductors. (*SEMATECH Strategic Overview*) While SEMATECH emphasizes production, there are no money-making products and relatively few ideas that member companies can use to their direct benefit. Evan and Olk described "product production" as one of the keys to measuring a consortium's success. This criterion, then, discredits SEMATECH as a consortium.

2. Analysis of SEMATECH Objectives

This section will discuss the eight original SEMATECH objectives and its six follow-on objectives. Objectives are used by organizations to set goals and expectations. These goals and expectations will later be used as a benchmark to measure their performance and determine their success. One point about "objectives" must be made. In many government organizations that depend on their overseer to insure their continued funding, Byron's Law of Objectives applies. Byron's Law is:

> Never create objectives that are not easily attained. In fact, it's better to understate your true expectations so that when you surpass your objectives, you appear to be more successful than originally hoped. In that light, each objective will be restated and analyzed.

a. Original Objectives

SEMATECH established eight original objectives in 1990. SEMATECH claims to have successfully accomplished all eight objectives.

Objective 1: Develop key process modules for member companies to integrate into proprietary process flows and products. Establish a baseline integrated process.

This objective was accomplished by establishing a baseline process with 0.8-micron, 0.65-micron, 0.5-micron, and 0.35-micron manufacturing capabilities. It appears that SEMATECH was more interested in the production technology than the actual process. SEMATECH supports this by stating that it concentrated more on the proprietary aspect and product development than on improving the process flows (*SEMATECH Accomplishments*). Harris Corporation left the consortium because SEMATECH fell short of its expectations in this area. The problem with this objective is that the "key modules" were somewhat subjective, which all but assured their completion.

Objective 2: Reduce member risk by delivering manufacturing processes and equipment modules for use in future equipment decisions.

SEMATECH accomplished this objective by developing three programs: (1) a single industry standard tool qualification; (2) a repetitive improvement program; and (3) a Cost of Ownership simulation software program. Each of these programs is designed to decrease the uncertainties associated with major business decisions. A "single industry tool qualification standard" requires more than the limited membership of SEMATECH for that standard to be observed

industry wide. Additionally, a tool guideline can become an industry standard without the existence of SEMATECH. It requires a commitment to that standard from the entire industry, not just SEMATECH members. The "repetitive improvement program" seems to be very similar to the TPM (Total Productive Maintenance) program advocated by Harris Corporation. Yet, Harris left the consortium citing the lack of commitment from SEMATECH to TPM as one of its reasons for departure from the consortium. The Cost of Ownership program is based on the "make or buy" decisions that many industries must consider. Although Gordon Alcott, a Technology Transfer Manager for Intel, cited the Cost of Ownership software to be very effective and one that his firm uses as an aid in decision-making (Alcott), such software is hardly leading edge and can easily be developed by a consultant for well under $100,000. Member risk, however, can only be reduced in major business decisions with proper management. These programs may aid management in decision-making, but themselves, do not reduce risk.

Objective 3: Develop at least one qualified, viable U.S. supplier for each key equipment module and manufacturing system.

SEMATECH claims to have accomplished this. This is a lofty objective with definitive criteria. The problem: who determined the list of key equipment modules and manufacturing systems? This

objective apparently does not include major suppliers. For example, the epoxy resin used to house semiconductors is not produced domestically and therefore must not be "key." (Carlton) Also, if SEMATECH supports a firm satisfying a specific demand, will that firm continue to survive without SEMATECH?

Objective 4: Develop long-term strategic alliances with selected suppliers to develop the required capability on the required time schedule.

SEMATECH claims to have accomplished this by pointing out that they have initiated over 51 Joint Development and Equipment Improvement Projects with 45 companies. It also cites the Total Quality program instituted at SEMATECH. Again, the problem: who determined the list of selected suppliers and its required time schedule, and what is the required capability?

Objective 5: Provide preferential availability of all funded equipment, systems, materials, supplies, and chemicals to the member companies.

SEMATECH says this objective is accomplished by giving its members the right of first acceptance of products and systems developed at SEMATECH. However, this objective could be used as a criticism of SEMATECH. T.J. Rogers said, "SEMATECH uses kick-back agreements to reduce the financial contributions of its members..." As an example he cites that SEMATECH-member companies purchase test equipment for SEMATECH that they would have likely acquired for themselves.

Objective 6: Drive standards and specifications for open architecture, computer-integrated manufacturing systems, including a generic cell controller.

This has been claimed as a success. The problem here is that this objective can easily fit into many other the high-tech industries. Other industries resolve standards either through a superior product, ones that establishes a standard itself (e.g., the personal computer operating system--MS-DOS), or through industry-agreed-upon protocols (e.g., the ISO standards for telecommunications). Open architecture is the trend throughout both the hardware and software fields of the computer and electronic industries. A computer company has the incentive to meet current industry standards to ensure that its products are compatible with both present and future systems. An organization such as SEMATECH is not needed to "drive standards and specifications for open architecture," or endorse "computer-integrated manufacturing systems." Also, this objective cannot be quantifiably measured. A further question: how does SEMATECH institute industry standards and under what authority?

Objective 7: Continue to provide a forum for open communication. Ensure timely information transfer.

This is another subjective criterion with no possible way to prove or disprove its accomplishment. SEMATECH presumably supports open communications among members, although that may be in question with all the litigation and law suits that member companies file against

each other for alleged patent and copyright infringements. But what about communications among the rest of the semiconductor industry?

Objective 8: Establish collaborative centers of manufacturing science at selected universities and national laboratories.

This was accomplished by naming 31 universities and national laboratories throughout the United States as SEMATECH Centers of Excellence (SCOE). SEMATECH directs many of their basic research projects to the SCOEs. One problem, it seems that this objective duplicates the mission for the Semiconductor Research Corporation (SRC).

b. Revised Objectives

New objectives were established in 1991 to set the stage for SEMATECH through 1997. Each new objective lists measurable criteria for evaluating success in each applicable "Thrust Area." From SEMATECH's viewpoint, the great thing about these new objectives is that many have already been accomplished. They must already be accomplished seeing that the original objectives were successfully completed.

Objective 1: Provide unit processes and generic manufacturing methods for members to integrate into their proprietary process flows and products.

This is the same as "Original" Objective 1.

Objective 2: Ensure that there is a viable supplier infrastructure capable of meeting the members requirements for key equipment modules, materials, and manufacturing systems.

This is the same as "Original" Objective 3.

Objective 3: Reduce sensitivity of cost to manufacturing volume.

In this objective, SEMATECH hopes to "hold semiconductor manufacturing cost of ownership constant at current levels in spite of increasing process sophistication and complexity." It also hopes to "reduce sensitivity of cost of ownership to factory capacity (penalty for 10X less capacity must drop from 50 percent to 25 percent)." (*SEMATECH Strategic Overview*, 1991, pp. 3-5,6) This objective defies economies of volume. Firms generally look for ways to exploit economies of volume rather than mitigate them. How can volume in a manufacturing process not affect the cost of the product? This objective is baffling. Why is this objective even desirable? If "reducing sensitivity of cost to manufacturing volume" were achieved, it would slow progress.

Objective 4: Provide programmable factory systems capable of responding to process changes with first-pass success.

This is similar to Objective 1, but it hones in on the Computer Integrated Manufacturing (CIM) program with which SEMATECH has been working with since its inception.

Objective 5: Cooperate with the Semiconductor Research Corporation, ARPA, and national laboratories to develop a research and educational infrastructure necessary to sustain United States leadership in semiconductor technology.

This is the same as "Original" Objective 8. One confusing thing in this criterion is "Cooperate with...ARPA." The measurable criterion

is to have "at least one ARPA program tool on the roadmap in 1994." (*SEMATECH Strategic Overview*, 1991, p. 3-8) There are currently no specific defense-related programs at SEMATECH. It's confusing because ARPA is the government sponsor of SEMATECH.

Objective 6: Maintain open forums for effective communications, collaboration, and consensus building with the SEMATECH community.

This is the same as "Original" Objective 7.

It appears that these objectives were designed more for public relations than to define SEMATECH's goals and missions.

3. VLSI and SEMATECH

SEMATECH was modeled after the highly successful Japanese Very Large Scale Integration (VLSI) consortium. This section will compare the two consortia based on both the seven generic criteria discussed earlier and on other factors.

ARPA sponsors SEMATECH (formally DARPA, but with "Defense" eliminated to appear more user friendly to commercial applications). As such, ARPA's function is similar to the role that MITI played with VLSI. Similar to VLSI, SEMATECH was initiated to enable the American semiconductor industry to compete effectively with the Japanese dominated memory-chip market. VLSI was initiated with specific objectives and upon their accomplishment was disbanded. SEMATECH was also initiated with specific objectives, but those objectives have been frequently changed and there seems to be no desire to dissolve the organization.

a. *Recruiting Personnel*

Recruiting personnel is similar for both consortia in that both use a combination of company and consortium personnel.

b. *Obtaining Resources*

Total funding for VLSI was $600.9 million (in 1993 dollars based on the producer price index) with the Japanese government providing $281.6 million. (Katz and Ordover, 1990, p. 176) Funding to date (from FY 1987 through FY 1993) for SEMATECH is $1.5 billion with the U.S. government contributing $757.0 million. The Japanese government funding was an interest-free loan; U.S. government funding for SEMATECH is an outright subsidy. The following table (figure 14) shows a comparison of VLSI and SEMATECH funding based in 1993 dollars.

VLSI's physical resources also differ tremendously from SEMATECH's. SEMATECH created its own $100 million facility where the majority of R&D is conducted. The SEMATECH factory accounts for approximately 56 percent of expenditures. Only 37 percent of its costs can be directly linked to R&D. (U.S. GAO, Jul 1992, p. 29) VLSI conducted all R&D at member company's research labs, thereby devoting virtually all funding earmarked for VLSI to applied research and development.

VLSI and SEMATECH FUNDING

VLSI

	Total Outlay (millions)			Government Contribution (millions)		
	Actual	1993 Dollars		Actual	1993 Dollars	
Year		(PPI)	(CPI)		(PPI)	(CPI)
1976	$ 80.0	$ 167.0	$ 195.6	$ 37.5	$ 78.3	$ 91.7
1977	$ 80.0	$ 157.1	$ 183.7	$ 37.5	$ 73.6	$ 86.1
1978	$ 80.0	$ 145.7	$ 170.7	$ 37.5	$ 68.3	$ 80.0
1979	$ 80.0	$ 131.1	$ 153.4	$ 37.5	$ 61.4	$ 71.9
TOTAL	$ 320.0	$ 600.9	$ 703.4	$ 150.0	$ 281.6	$ 329.7

SEMATECH

	Total Outlay (millions)			Government Contribution (millions)		
	Actual	1993 Dollars		Actual	1993 Dollars	
Year		(PPI)	(CPI)		(PPI)	(CPI)
1987	$ 200.0	$ 238.5	$ 253.9	$ 100.0	$ 119.3	$ 126.9
1988	$ 200.0	$ 232.8	$ 243.8	$ 100.0	$ 116.4	$ 121.9
1989	$ 200.0	$ 221.3	$ 232.6	$ 100.0	$ 110.6	$ 116.3
1990	$ 200.0	$ 210.9	$ 220.7	$ 100.0	$ 105.4	$ 110.3
1991	$ 200.0	$ 206.6	$ 211.7	$ 100.0	$ 103.3	$ 105.9
1992	$ 200.0	$ 204.0	$ 205.6	$ 100.0	$ 102.0	$ 102.8
1993	$ 200.0	$ 200.0	$ 200.0	$ 100.0	$ 100.0	$ 100.0
TOTAL	$1,400.0	$1,514.1	$1,568.3	$ 700.0	$ 757.0	$ 784.1

"Actual" are approximate amounts in the case of SEMATECH; "PPI" is the Producer Price Index for finished goods; "CPI" is the Consumer Price Index.

Figure 14: This table shows the dollar amounts the Japanese and the American governments contributed to VLSI and SEMATECH respectively for comparison. What the table does not show, however, is how much of that money was devoted to actual R&D. It is this author's opinion that the VLSI investment represented more R&D dollars than does SEMATECH. According to GAO, only 37 percent of SEMATECH's budget is directly attributed to R&D.

SOURCE: *Economic Indicators*.

c. Recruiting New Members

Membership was not a factor with VLSI. It had only five members. All members were fully committed for the entire project and they never intended to expand that membership. Membership was initially not an issue with SEMATECH. But after three members have left and the consortium eyes funding and support into the 21st century, one would expect attracting new members to be a priority. According to SEMATECH Communications Manager, Michele Higdon, new members would be welcome, but SEMATECH is not actively seeking nor does it necessarily desire new members. (Higdon)

d. Decision-making

VLSI was successful in part because it's objectives were limited and well defined in terms of technical goals, funding, and lifespan. Thus, the need for on-going decisions was limited. In contrast, SEMATECH has modified its technical goals and life-span. This significantly complicates SEMATECH's decision-making process.

The decision-making process for the two consortia is also quite different. MITI divided the objectives among the participating companies and each company collaborated with researchers from MITI's Electro-Technical Laboratory (ETL). MITI also assigned specific tasks to the participating labs. The Japanese company working on specific projects and tasks had the most influence on their outcome, as VLSI was much less hierarchically structured. SEMATECH has several

more layers than VLSI with both the House and Senate models of decision-making. Therefore, SEMATECH-member companies have less influence on the direction of SEMATECH than the Japanese companies had with VLSI.

SEMATECH cannot be judged successful due to its decaying membership, changing objectives, and quest for indefinite continuation. SEMATECH may have been modeled after VLSI upon its inception, but there is no resemblance to the Japanese consortium today.

4. JESSI and SEMATECH

JESSI is hailed as the last resort for the European Community to be able to effectively compete in the worldwide semiconductor market. JESSI is designed as a colossal *defi Europeen* in response to the American challenge. (Gilder, 1989, p. 320) JESSI's structure is similar to SEMATECH, with two major differences. First, JESSI smothers its members, preventing them from participating in joint ventures with companies outside JESSI. The rationale is to avoid spillovers and unauthorized technology transfers. SEMATECH, although wary of joint ventures, does not discourage these practices. Second, JESSI's budget is more than twice that of SEMATECH. This increases the burden on JESSI member companies. They must account for $200 million in dues, or an average of $25 million each. This means that considerable potential internal R&D funding is lost. Finally, despite its focus on generic or pre-competitive research, JESSI has yet to be affiliated with academia. On the other hand, SEMATECH contributes significantly to academic institutions through research grants.

The results for the European semiconductor manufacturers are obvious. They're playing an impossible catch-up game. The innovations required to create high profit-margin products cannot occur when their emphasis is on generic or pre-competitive research. This is not as drastic for SEMATECH, primarily because SEMATECH member companies are very large and their SEMATECH contributions have little effect on their internal R&D.

JESSI, like SEMATECH, is seeking an "indefinite" extension beyond its 1996 expiration date. Research goals are now "refocused" on potential high-growth technologies. Additionally, there is a significant effort to increase cooperation between SEMATECH and JESSI. (Lineback and Dunn, 16 Nov 92, p. 7)

In terms of success and effectiveness, SEMATECH appears more along the lines of JESSI. It has very little to show for the immense amount of tax dollars spent. Cooperation between two organizations with limited success may not be the best approach for the 21st century.

III. JUSTIFICATION FOR GOVERNMENT SUPPORT

This chapter examines government subsidies and their effects on research and development. It looks at the market imperfections associated with R&D. It discusses the semiconductor industry, and the public welfare that is realized in both R&D and industry. It concludes with rules of thumb for government intervention.

A. RESEARCH AND DEVELOPMENT

The U.S. government provides significant R&D funding in this country. American R&D is traditionally either commercial, defense, or federal non-defense. Defense and R&D programs for other federal interests are public sector technologies.

Several justifications for government intervention in R&D have been suggested. They are: (1) non-appropriability, (2) preservation of specialized providers, and (3) indivisibility.

1. Non-Appropriability

Appropriability imperfections occur when a firm is unable to take advantage of all the benefits accruing from its R&D projects. If imitation is easy or the development can be manipulated by another firm, it is not appropriate for a firm to invest in R&D in that area. This is one of the justifications given for federal participation in basic R&D. Another example is in the case of generic research. A firm conducting generic research may appropriate only a small portion of its efforts, if any. Therefore, non-appropriability is a potentially good justification for

government intervention in R&D. Two additional factors that often arise in discussions of appropriability are uncertainty and time.

a. Uncertainty

Uncertainty is internal to the organization when it concerns the project's technical outcome; it is external to the organization when it concerns the future market in which the technology must compete. Internal and external uncertainties influence a firm's investment decisions and the corresponding development strategies. Internal uncertainties are ones that a company may be able to control. They can be reduced by investing in research to create additional knowledge and information from which calculated decisions can be made. Some additional information can be accrued through engineering and marketing studies, while other data accumulates as the project advances through the research and development cycle. "At each stage of the R&D process, decision makers must consider the tradeoffs between investments in R&D and the value of the knowledge created in order to determine whether to continue the R&D project and at what level." (Gates, 1988, p. 28)

On the other had, external uncertainties are those generally beyond the firm's control. External uncertainties are normally weighed and evaluated through informed judgements and probability theory. Uncertainty in R&D is also often accompanied by high risk. This is especially true in "high-technology" projects. Many in industry justify federal participation in high-risk R&D because the government can more readily absorb R&D failures. (Gates, 1988, p. 28) The

potential non-appropriability of the R&D also contributes to uncertainty. But uncertainty does not contribute by itself to non-appropriability. Uncertainty is always a factor in R&D.

b. Time

Changes in project duration affect both expected costs and benefits of R&D. A project may be obsolete when it enters production due to rapid technological changes or imitation of the product by competing firms. This will decrease a technology's value of time. Concurrently, demand and market size may increase over time. "Time-related demand shifts can either increase or decrease a technology's value; overall, expected benefits generally decrease as time increases." (Gates, 1988, p. 29) Time can also result in high risk. Benefits from R&D can be non-appropriable due to time, but this risk will always occur. The "time" issue does not, in itself, justify government intervention.

2. Preservation of Specialized Providers

Government typically supports industries that have little competition and that are thought to fulfill a niche important to national security. Many government officials and politicians think that without this support, that particular industry would cease and national security might be compromised. The semiconductor industry is a highly competitive, globally-integrated, high profit-margin industry. Seldom have chip makers avoided business opportunities simply because those opportunities crossed lines of demarcation. It is because the semiconductor industry is globally integrated

that various parts and materials have left American shores. American chip makers are business people who purchased certain items or services overseas because of better value to their companies. Therefore, even though some of the products in this industry are not produced domestically, they are produced and are available to American industry. Even in the event of war, some producers of these items would be willing to sell to U.S. firms.

An excellent example of how the American industry responds to products suddenly becoming unavailable is its reaction to the 4 July 1993 fire of the Sumitomo Chemical Company in Japan. Sumitomo produced over sixty percent of the world's epoxy resin supply used in semiconductor housing. Dupont was the remaining domestic producer of that resin when it shut down production in 1989. Since the fire, several American companies have re-considered producing epoxy resin. Meanwhile, as their inventories dwindle, the industry (led by Motorola and AMD) is looking at alternative housing methods (i.e., ceramics) and exploring alternative chip packaging means to preclude other supply problems. (Carlton, J.) (Gross, N.)

3. Indivisibility

"Indivisibilities arise where it is impossible or prohibitively expensive to divide a large R&D project into smaller tasks that can be funded by smaller individual firms." (Carpenter, 1990, p. 8) Smaller firms in the semiconductor industry are generally unable to commit the capital necessary to conduct the R&D required for the next generation of computer chips. One argument for SEMATECH is that large scale R&D cannot even be properly funded by the larger companies. That argument for

SEMATECH is weak. If the returns for large scale investment are appropriable, then the project will be funded. Besides, the amount of capital devoted to R&D at SEMATECH pales in comparison to the R&D capital of many of its members (e.g., $5.2 billion for IBM verses less than $200 million for SEMATECH).

B. COMMERCIAL VERSUS PUBLIC TECHNOLOGY DEVELOPMENT

Commercial technology development differs from basic R&D and public sector technology development. Industry has choices as to which commercial technology they invest in based on profit potential in the private market. Often, public sector technologies do not. Commercial technologies must be technically and economically competitive to be attractive to the consumer. Another difference is that independent R&D initiatives are likely to be significant, particularly as technologies approach commercialization. Federally supported commercial R&D projects are apt to displace or duplicate many private efforts. (Gates, 1988, pp. 27-28)

Assume that the semiconductor industry has changed little historically. In this case, the basic justification for government-subsidized R&D is the overall public good that results from technical breakthroughs in basic research and development. Private investment in basic R&D in these areas tends to be unattractive. The rate of return for significant investment into basic R&D does not justify its expense for private firms. A private firm typically conducts R&D in areas that may result in new products. In these cases the tendency is to keep results internal to the company, hoping for the greatest return for its R&D investment.

The type of research conducted by private firms depends on the appropriability of that research. The appropriability for basic research conducted by individual companies is difficult to measure and perceived to be low. Results from basic R&D are quickly disseminated throughout the scientific community. In addition, these results generally have applications that exceed the scope of any single firm or industry. Consistent with this view, SEMATECH should focus on basic or generic R&D where the results are dificult to appropriate.

C. TYPES OF FEDERAL SUPPORT

Government subsidization of research and development can be executed in one of four ways:

1. through direct funding of an organization designed to conduct specific R&D;
2. through tax credits for incremental research and experimentation to cover the costs of collaborative research;
3. through procurement of specified products or systems; and
4. through research grants to individual firms for specified projects.

Tax credits and procurement tend to be less intrusive and usually allow free market incentives to function better. Richard Nelson broke down the subsidization issue and distinguished among four kinds of government R&D support programs (Nelson, 1982, p. 458):

1. those associated with public procurement or other well-defined public objectives,
2. those that involve an extension of support for scientific basic research to advance generic technological knowledge,

3. those that are aimed at meeting reasonably well defined clientele demands, and

4. those that attempt to support "winners" in commercial competition.

Critics have argued that many of the government sponsored R&D programs have been inordinately expensive and wasteful. This is typically the case for category four, programs that support winners in commercial competition. Contributions to the advancement of civilian technology created by defense and space programs are "spillovers" from well-defined public objectives to commercial products. Certainly commercialization was not the principal intent of these programs. The advance of civilian technology was the central purpose of government R&D support programs in agriculture and basic biomedical research. This research typically addresses generic technical knowledge. The rate of return on the public investment in R&D for agriculture undoubtedly has been very high. But the rate of return in other programs, such as the supersonic transport, the solar energy industry, and AMTRAK, among others, have been disasters and are regarded as failures. Projects like these create the perception that government R&D is wasteful. (Nelson, 1982, p. 470; Gates, 1988)

There is a problem with government subsidization of commercial R&D. Product related R&D in the semiconductor industry is appropriable. The chip-making business is highly competitive, globally integrated, and responds to the free market. Semiconductors represent the "tip of the spear" concerning the technical revolution. The only chance for a semiconductor firm to remain profitable is through innovations and process improvements. Innovation requires individual commitment to research

and development programs. Hence, the incentive to invest in R&D in the semiconductor industry is naturally very high due to the dependence on innovation to ensure high-profit-margin products.

The federal government substantially supports basic and public-sector-related, semiconductor R&D. "Federal agencies have been involved in the U.S. semiconductor industry since its inception and have contributed to its competitiveness." (United States Congress, Sep 87, p. 3) The Department of Energy's National Laboratories have research programs on semiconductor materials and processing, as do the National Science Foundation and the National Bureau of Standards. Besides funding through ARPA, each military agency also supports research in the semiconductor industry. So the question remains, does the semiconductor industry require further federal support to remain competitive? Does government support of the commercial semiconductor industry reduce the chip makers' incentive to invest in basic R&D?

Until the formation of SEMATECH, it was argued that the federal funding of semiconductor R&D created a gap in research not covered by semiconductor firms or their equipment suppliers. The government emphasized basic research and R&D benefitting the military, nuclear power and other public sectors; semiconductor companies concentrated their R&D on solving current problems or providing background for their next manufacturing facility. (United States Congress, Sep 87, p. 5) SEMATECH was envisioned to create an environment where the government and

major semiconductor firms combine their funding to close the gap between federally sponsored research and the research of the private firms.

SEMATECH proponents argue that independent private investment in these research areas is cost prohibitive. But, they agree, if a firm has to only invest a minimal amount in a collaborative effort and can reap all the benefits of that organization, it will be financially attractive. To justify federal support, SEMATECH's research results must be non-appropriable. However, SEMATECH's exclusionary membership policies and licensing agreements suggest that these results are appropriable. Furthermore, international diffusion of SEMATECH's research is likely to occur first through international joint ventures with SEMATECH members. This represents an "intentional" spillover; it is not an "unintentional" spillover expected from basic research. For these reasons, government support for SEMATECH is not justified. Federal support of R&D does not necessarily increase U.S. competitiveness; in fact, it may decrease the incentive for independently funded basic R&D.

D. INDUSTRY

The government has had a history of supporting targeted industries, from agriculture to railroads. (Brister) While there may be some success stories, several blunders have wasted large amounts of public funds. The basic problem with allocating federal funds to support a specific industry is that the process does not respond to market requirements. It responds more to bureaucratic empire building

and political payoffs. Don Valentine, founding venture capitalist and a director of Apple computer and currently a director of Cisco Systems, argues against government support and a free market: "The world of technology is complex, fast changing, unstructured, and thrives best when individuals are left alone to be different, creative, and disobedient." (Rogers, 25 March 1993)

Government support is generally associated with government regulations and control. Many private companies prefer to conduct their business within the limits of the law without government support and its associated restrictions. T.J. Rogers argues that it is only through free markets that companies adjust to market conditions to ensure that they remain competitive. Government support inhibits these necessary adjustments, sometimes to the point that the industry or company is effectively eliminated.

Government officials often hope, when determining the best way to support industries, that their involvement preserves normal market incentives. But if federal support reduces a company's incentive to fund areas which the company would have funded anyway, government involvement is misdirected. Normal market incentives must be maintained.

E. GOVERNMENT INTERVENTION RULES OF THUMB

Summing up government support for the semiconductor industry, Brink Lindsey's "DRAM SCAM" article appropriately points out that SEMATECH only

reaffirms some rules of thumb regarding direct and indirect government support (Lindsey, Feb 1992, p. 48):

> Rule number one: Whenever government decides to step in and "help" an industry, the effect, whether intentional or not, is usually to preserve the status quo and stifle beneficial change. This isn't because bureaucrats are stupid; it's because of the nature of politics. Government naturally favors interests with political clout, which means interests that are well-organized and well-funded. Accordingly, the political contest between industry giants--with their trade associations and Washington offices and PR offensives--and the entrepreneurial start-ups that are trying to upend them will always be a skewed one.
>
> Rule number two: "Strategic" industries are a dime a dozen. Every decent lobbyist can come up with several plausible-sounding reasons why the industry he represents is a linchpin of American economic strength and must therefore be preserved at all costs. The only real validation of such claims, though, is ongoing wealth-creation and growth. And if an industry meets this definition of "strategic," it doesn't need government help.
>
> Rule number three: Patriotism is the last refuge of scoundrels. National security may indeed take precedence over economic considerations, but arguments that the free market is undermining us militarily should be assessed skeptically. In most cases, what is at stake is the security of special interests, not the nation.
>
> Rule number four: Nothing lasts forever, but "temporary" federal assistance comes close. Whenever government does intervene in an industry, there is almost irresistible pressure for it to remain there. Not only do beneficiaries within the industry become addicted to government support, but bureaucrats become convinced that the industry can't run without them.

Government support of the semiconductor industry through SEMATECH illustrates these rules of thumb.

IV. SEMATECH AND ITS IMPACT

This chapter discusses SEMATECH's impact since its inception and its role in the recent recovery of the semiconductor industry. It also discusses the unavoidable effects of technology spillovers and the relationships of SEMATECH member companies with foreign firms through joint ventures. This chapter concludes with some thoughts on the future of SEMATECH.

A. RECOVERY OF THE SEMICONDUCTOR INDUSTRY

Concerning the R&D process, SEMATECH is far too young to have yet had an impact on the current success of American chip producers. The amount of time it takes for strides in the research laboratories to reach the market place is at least three years. (Okimoto, 1984, p. 81) SEMATECH was initially funded for five years, ending in 1992. The funding justification anticipated that industry improvements would be realized after completing the fifth year with the third "phase." (United States Congress, Sep 87, p. 40) The industry turnaround actually began in 1989, without SEMATECH. Some observers have noted correctly that part of this turnaround is due to the 1986 U.S.-Japanese trade agreement (renewed in 1991) to hamper competition from Japanese chip producers. However, the major success for U.S. firms has not been in these low-profit-margin chips in which competition has been restricted. Indeed, the major U.S. success has been in proprietary microcomponents that use semiconductors as an input. This success is all the more

striking because the 1986 trade agreement substantially raised the cost of this input. So none of the U.S. success in proprietary microcomponents can be attributed to the 1986 agreement. What then was responsible for the U.S. success in proprietary microcomponents? Certainly not SEMATECH because of the lag noted above. The most likely cause of the U.S. success is the stepped up enforcement of property rights in intellectual products.

> U.S. semiconductor manufacturers (presently) enjoy increased profitability as the industry continues to shift attention away from commodity products toward higher margined proprietary products. The establishment of the U.S. Court of Appeals for the Federal Circuit in Washington, D.C. by Congress in 1982 cleared the way for the development of proprietary chip designs. The court was specifically designed to hear patent cases. (*Standard and Poor's*, p. E15)

Prior to 1982, patents were successfully challenged at a rate of 70 percent. After 1982, patents in the United States have been more vigorously enforced. The incentive after 1982 to produce proprietary products increased. As a result, American firms dominated proprietary microcomponents; this was prior to the 1986 trade agreement, and before SEMATECH started. Intel Corporation, for example, specializes in proprietary microcomponents. Intel has led the resurgence of the American industry and is currently the number one chip maker in the world. (*Standard and Poor's Industry Surveys*, "Electronics Current Analysis") Figure 15 shows the top suppliers of microcomponents. Figure 16 shows growth of the top microcomponent firms. Note that the American companies in this market had uniformly double-digit growth compared to the top foreign companies.

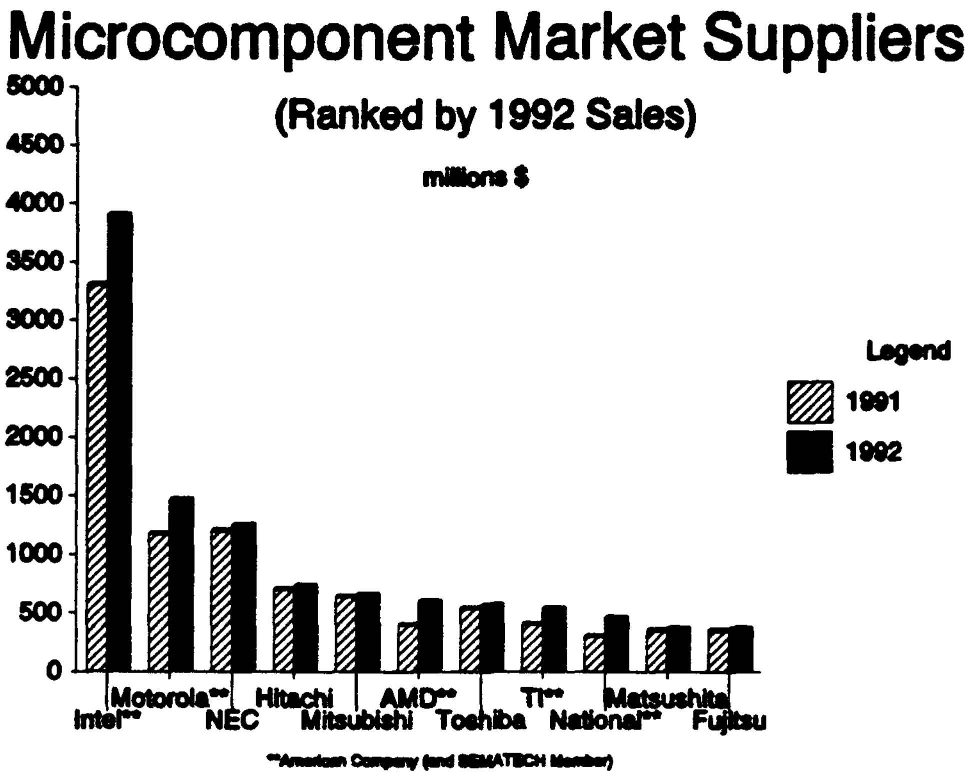

Figure 15: U.S. companies currently hold a 59 percent microcomponent-market share. Intel alone had a 29 percent market share in 1992.

SOURCE: *Standard and Poor's Industry Surveys*.

There is no question that the American semiconductor industry has made a comeback, led by Intel. The hallmark of Intel's success is innovation highlighted by 80X86 microprocessor monopolies. For example, Intel's 80386 CPU chip

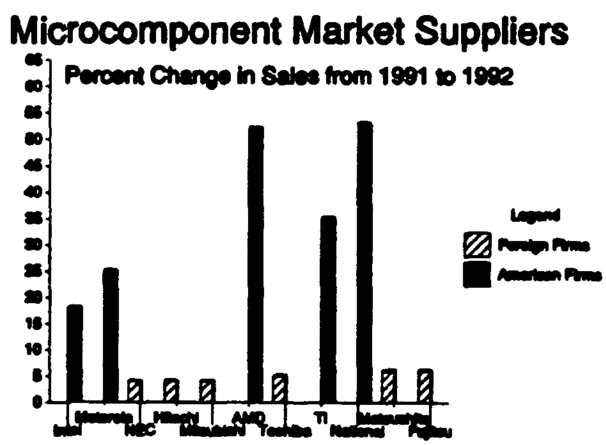

Figure 16: Note the double-digit growth for U.S. firms.

SOURCE: *Standard and Poor's*.

cost less than two dollars to manufacture in 1988. Intel sold those chips for $300 wholesale, a markup of 1500 percent. (Gilder, *Microcosm*, p. 183) These and similar leading edge products blazed the trail for current American success in the semiconductor industry. These products all took considerable research, development, testing and evaluation (RDT&E). Coupled with that innovation were the necessary restructuring and manufacturing improvement programs initiated by companies that suffered through difficult years in the mid-1980s. The SEMATECH consortium is not old enough to have played a part in these innovations. SEMATECH initially concentrated on memory chip production. The American industry ignored this and instead concentrated on microcomponents. SEMATECH soon followed suit and abandoned memory chip production. It developed new missions and objectives in 1990. Concentration on proprietary products and industry restructuring are the reasons for the industry turnaround.

SEMATECH has made positive contributions. SEMATECH has complemented the American semiconductor industry restructuring and "right sizing" with its Total Quality Management (TQM) program, its emphasis on computer integrated manufacturing (CIM), and overall process improvement programs (though not to the Harris Corporation's satisfaction). SEMATECH has also emphasized improving the supplier infrastructure. It has done this by funding selected American companies in different research efforts to preserve and revive the U.S. technology pool. SEMATECH's assistance to equipment suppliers is premised on the "food chain"

theory: non-competitiveness in the equipment industry leads to non-competitiveness "up the food chain" in the chip industry.

This is interesting because Craig Fields, former DARPA director, was dismissed for providing Gazelle Microelectronics $4 million. Gazelle needed a capital infusion to stay in business and prevent direct foreign investment. Fields was eased out of office because the Bush administration opposed interventionist industrial policies. (Zieglar, 1992, pp. 175-176) In other words, it was imprope for DARPA to intervene in industry, but it was acceptable for SEMATECH to invest in suppliers.

SEMATECH also showed that it was no better than general government experience in picking industry winners. SEMATECH pumped more than $70 million into GCA Corporation of Massachusetts to re-establish it as a technology leader in photolithography. This would contribute to the SEMATECH headliner, the 0.35 micron chip producing machine (a micron is one-one millionth of a meter). Due to its development of the 0.35 micron etching machine, GCA was a SEMATECH success story. An American company appeared ready to take the lead in an area dominated by Nikon and Canon of Japan. However, the fruits of this development would not be realized for several years. Despite its recent R&D success, GCA was sold in May 1993, by its parent company General Signal Corporation due to the continual losses posted by GCA and its inability to crack a Japanese dominated market. ("SEMATECH-Backed Firm Near Failure," 30 April 1993, p. 1G)

SEMATECH has had little to do with the semiconductor industry's success. Even if its investments in long term technology pay off, its role in the recent

turnaround has been negligible. Many believe that SEMATECH has hindered developments in chip making by supporting older, more-established, billion-dollar giants over innovative newcomers. SEMATECH attempts to pick winners and losers in the semiconductor industry. SEMATECH has shown that even as insiders, it's difficult to pick winners and losers in business. As Brink Lindsey puts it, "...the bureaucrats have backed the wrong horse. Within the sunrise industry of microelectronics, the government has managed to locate and subsidize the sunset companies, to the detriment of those young and dynamic companies that represent the industry's future." (Lindsey, Feb 1992, p. 48)

B. THE FUTURE OF SEMATECH

The success or failure of SEMATECH is difficult to determine. One thing is certain, SEMATECH is not a consortium. It seems to be a government-industry partnership that attempts to please as many constituents as possible by spreading its budget throughout the United States. It has funded projects in approximately 30 states involving over 200 sites.

> The budget of an individual project determines whether it is part of the technology pork barrel. The relevant budgeting threshold is when projects become politically relevant on expenditure grounds to a sufficient number of politicians, or to sufficiently important politicians (such as committee chairs or other legislators with important responsibilities in Congress). (Cohen and Noll, 1991, p. 381)

The point is that SEMATECH is not a consortium and should not be portrayed as such. T. J. Rogers, CEO of Cypress Semiconductor, and an outspoken critic of SEMATECH said, "(SEMATECH) equates the health of our industry with the

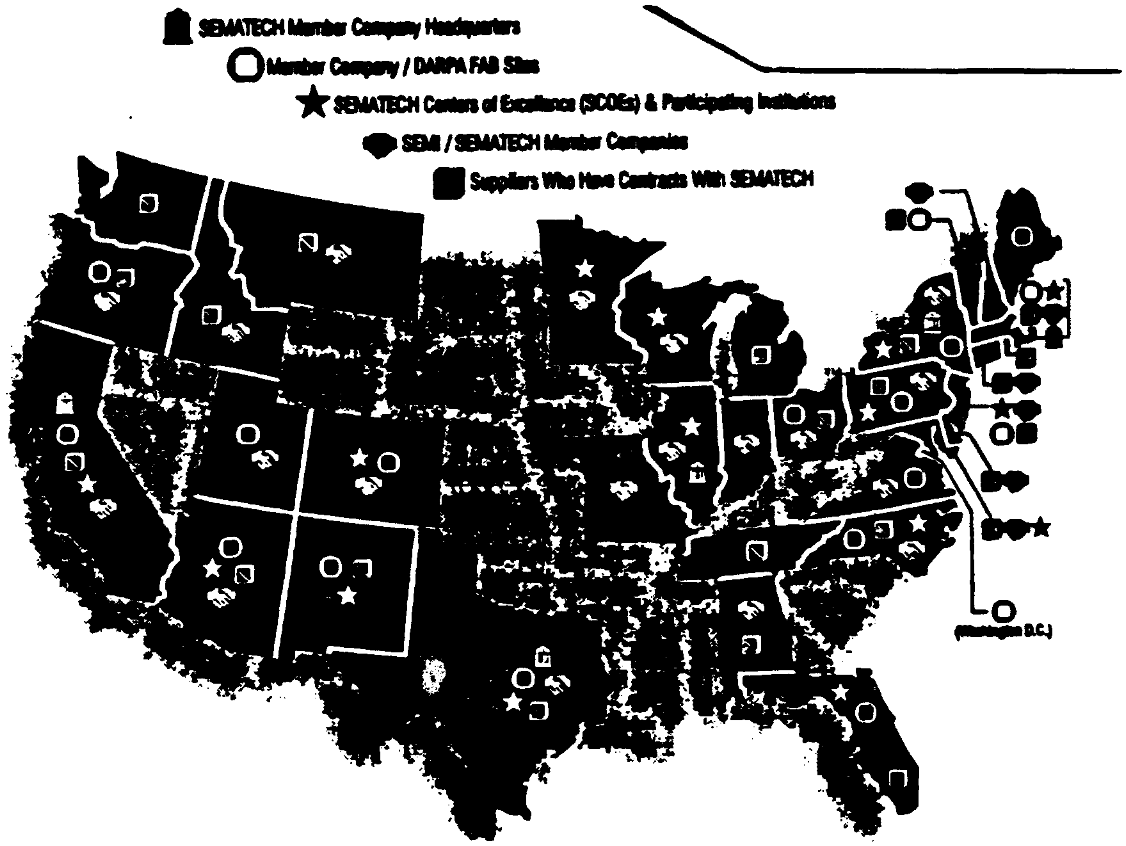

Figure 17: This shows where SEMATECH funds are spread throughout the country.
SOURCE: *SEMATECH Success*.

fortunes of a handful of giant companies, some of which are models we should avoid following--the companies that lost market share to the Japanese to begin with." (Rogers, 23 Jul 1991)

SEMATECH is not a good model for government-industry partnerships. This is due mainly to four reasons: (1) SEMATECH has an indefinite future; (2) SEMATECH has no concrete goals or objectives; (3) SEMATECH depends on grants rather than loans; and (4) SEMATECH has little incentive to maximize potential

benefit of those tax dollars. Worst of all, SEMATECH further promotes and encourages special interests to seek out the same type of government funding and support for their industry.

Research and Development programs seldom have an immediate impact on any industry. Effects of R&D are typically long-term. Additionally, SEMATECH has made it clear that preservation of the American vertical infrastructure is a priority. Reshaping and restructuring the semiconductor infrastructure into a viable, self-sufficient entity seem inconceivable in five short years.

As for the future, SEMATECH is at the forefront of American industrial policy and will likely continue to be funded at least through 1997. Dual-use technologies are now the watch-word for DoD funded R&D. [NOTE: Dual-use means that the technology is applicable to both military and commercial sectors.] This is a marked turnaround from the noninterventionist policies of past administrations. Sales of semiconductors was expected to grow at a nominal eight percent rate through the turn of the century. Sales actually grew by a nominal rate of 17 percent for 1992. (*Standard and Poor's Industry Surveys*) The expected growth, the recent recovery of American semiconductor manufacturers, and the latitude of funding by SEMATECH have won support for SEMATECH in Congress and other arenas. Additionally, it is highly unlikely that SEMATECH will fail in attaining its objectives.

SEMATECH is firmly entrenched in current public policy and will most likely continue to receive federal support.

V. SEMATECH AND POLITICS

Politics and SEMATECH cannot help being intimately related, not only because SEMATECH receives federal funding, but because of the current emphasis on industrial policy and "dual-use" defense technologies. The defense budget is shrinking and U.S. defense research and development is being restructured in light of changing defense requirements, but funding for RDT&E remains relatively constant. (Nunno, 20 Aug 1992, p. CRS-2) Thus, the Department of Defense remains a potpourri of available funding to R&D.

This chapter discusses the defense industrial base and whether the government is responsible for maintaining that infrastructure. It then examines why SEMATECH is sponsored by DoD through ARPA. If there is so much emphasis on basic or pre-competitive R&D and dual use technology, why is SEMATECH administered by DoD? Is this in DoD's best interest? This chapter will conclude with an analysis of DoD's responsibility to industry.

A. THE DEFENSE INDUSTRIAL BASE

The defense industrial base is a tremendous vertical infrastructure of manufacturers and suppliers fulfilling all of DoD's procurement and service needs. Considering the ever-increasing globalization of the worldwide manufacturing base, many in this country perceive that foreign defense procurement erodes the domestic capability to provide those items. This perception was illuminated in the early 1980s

by a Congressional study that showed how many parts on an F-16 fighter, for example, were produced overseas. This issue received much attention because of the potential impact that the cessation of overseas procurement might have on our military technological advantages.

After Japan began to dominate commodity-type memory chip production in the 1980s, it competed virtually all American DRAM producers out of the DRAM business. DRAMs and integrated circuits are the backbone of U.S. high-tech arsenals. This foreign dependence on memory chips is what prompted lobbyists from the semiconductor industry to seek out and receive increased government subsidies. In particular, it was the basis upon which SEMATECH was founded. Justification for this federal assistance was to maintain the "semiconductor defense industrial base."

This "save our defense industrial base" mentality permeates all sectors of American industries that are losing ground to foreign competition. Many are looking for federal support to protect their niche even though they provide more expensive, and in some cases lower quality, products than those available on the world market. "In the interests of national security" are some of the sweetest words to an American company specializing in defense-type products. It means that the government will pay its price. It means it is likely it will maintain a large contract. It also means that its production will be owned by Americans and located on American soil.

This mentality is certainly not valid in the commercial market. In almost all cases, the commercial market is a world market with global competition. This ensures the best valued product to the consumer. With unyielding support for the

defense industrial base, DoD is cheated by not being able to procure products with the best value. Benjamin Zycher wrote:

> Many people worry that foreign procurement makes the United States vulnerable to a cutoff in items supplied by foreigners. They fear that cuts in foreign supplies may exceed, in both number and variety, potential cuts in supplies from domestic firms. That view is misguided. Suppose that some defense good is purchased from foreign suppliers and that this arrangement is subject to easy but unpredictable cutoffs. Suppose, also, that such interruptions are easy to insure against (with stockpiles, alternative suppliers in other parts of the world, or excess production capacity in the United States). If so, then foreign dependence does not cause true vulnerability. The key question, therefore, is not the source of the defense goods, but rather the ease with which interruptions in supply--either foreign or domestic--can be insured against. If domestic dependence is more difficult to insure against than foreign dependence, then ironically, domestic dependence causes greater vulnerability. (Zycher, 1993, p. 693)

Granted, there are cases in which national security is an issue, but those exist only in the most top-secret or black programs. Black programs may initially require sole-source procurement to assure secrecy. Black programs are exempt from market realities with regards to contractors and funding. In many cases, their preservation is justified as being in the best interest of the United States. Yet, domestic production is not truly required for all black program components; for example, a black project may use foreign semiconductors as long as their use is not specified. This is likely the scenario in many black projects.

The idea of maintaining the defense industrial base in the interests of national security is dubious. It is largely promoted by companies that are unable to effectively compete globally. Aaron Friedberg wrote:

> Of all the industrialized nations, defense planners in the United States have agonized most in recent years over how to deal with the globalization trend. For much of the half century after 1945, the United States was able to enjoy a

> position of virtual autonomy in defense production. The sheer size and relative technological sophistication of the U.S. economy make it possible to efficiently produce almost everything necessary for defense. And this result, so reassuring from the point of view of military security, was achieved without extensive government efforts to plan and manage the nation's economy. (Friedberg, 1992, p. 69)

Nothing stays the same; the world economy has changed.

Never once in our history has our military effectiveness been compromised because crucial parts or services have been denied by foreign producers. (Moore, G.D.) Major military confrontations in the last two decades have been swift and decisive. As in other conflicts, the Desert Storm effort relied primarily on inventories for spare parts. American industry began to respond to demands placed on them by the military in the Persian Gulf. When called, industry largely satisfied the need. The idea that the defense industrial base is at risk is a myth that is largely perpetuated by organizations such as the Semiconductor Industry Association (SIA) and other special interest groups, that have convinced our legislators to subsidize them in order to preserve their companies. The "defense industrial base" has been entrenched in our vocabulary as can be seen by the complex web of defense R&D funding through the Department of Defense Technology Base Program. Defense protectionism was once the policy, albeit an inefficient one, when American industry's ability to support sudden and sustained increases in military production could potentially prove decisive in defeating the Soviet Union. That global threat has subsided and defense protectionism should die with it.

Overtly preserving the "defense industrial base" limits DoD in its ability to be a market consumer. With declining budgets and a shrinking military, DoD must demand value in all appropriations and expenditures. DoD must act and be treated like a free-market consumer.

B. DOD AND SEMATECH

SEMATECH is sponsored by DoD through ARPA. The diminishing domestic memory market and the woes of American semiconductor manufacturers enabled the SIA to effectively lobby for SEMATECH in the name of national defense. The objective was to prevent the memory-industrial base from shifting overseas. SEMATECH's focus has evolved. For SEMATECH to remain in legislative favor and justify funding, its new battle cry is preserving the industrial infrastructure and keeping jobs in this country. In all its public relations literature, SEMATECH emphasizes these ideas so much that the literature reads like propaganda. SEMATECH's national security connections are given limited emphasis. In *SEMATECH Accomplishments* (1992), SEMATECH's direct contributions to the DoD are not explicitly noted. Instead, the different military systems that include products manufactured by SEMATECH-member companies are noted. Upon quick review, it would appear that SEMATECH is responsible for those contributions.

It's not entirely clear that SEMATECH's interests are in defense. It seems more probable the SEMATECH is interested in keeping its yearly $100 million

government grants. So the question is, if SEMATECH is to continue receiving federal funds, why are those funds syphoned from DoD?

In 1987, when SEMATECH was initiated, there was strong sentiment that it was a commercial venture and that government support should not be channelled through DoD and DARPA.

> SEMATECH is being conducted under cover of national defense, rather than economic necessity, which handicaps it from the start. What the military often wants in a semiconductor chip (unsurpassed performance under conditions of conflict) is not what civilian industry needs (reliability and low cost). (Dertouzos, 1990, p. 10)

This general feeling raises an important point. DoD's and commerce's interests n semiconductor technology are not entirely compatible. DoD may benefit from chips with those properties desired in the civilian market, but the commercial market is not interested in paying the added costs for DoD-demanded durability. The departure of Harris Corporation from SEMATECH further illustrates this incompatibility. Harris has been the military's number one supplier of semiconductors for several years. (*Standard and Poor's*)

SEMATECH is funded by DoD because the Department of Defense has the single largest federal RDT&E budget, $38 billion. (Nunno, 20 aug 1992, p. CRS-3) ARPA accounts for 22 percent of that budget. Department of Defense RDT&E is totally discretionary funding that is earmarked for high-risk technology. (Davey, 21 Apr 1988, p. CRS-73) SEMATECH currently concentrates on management and the manufacturing process; these are not high risk technologies that promote quantum

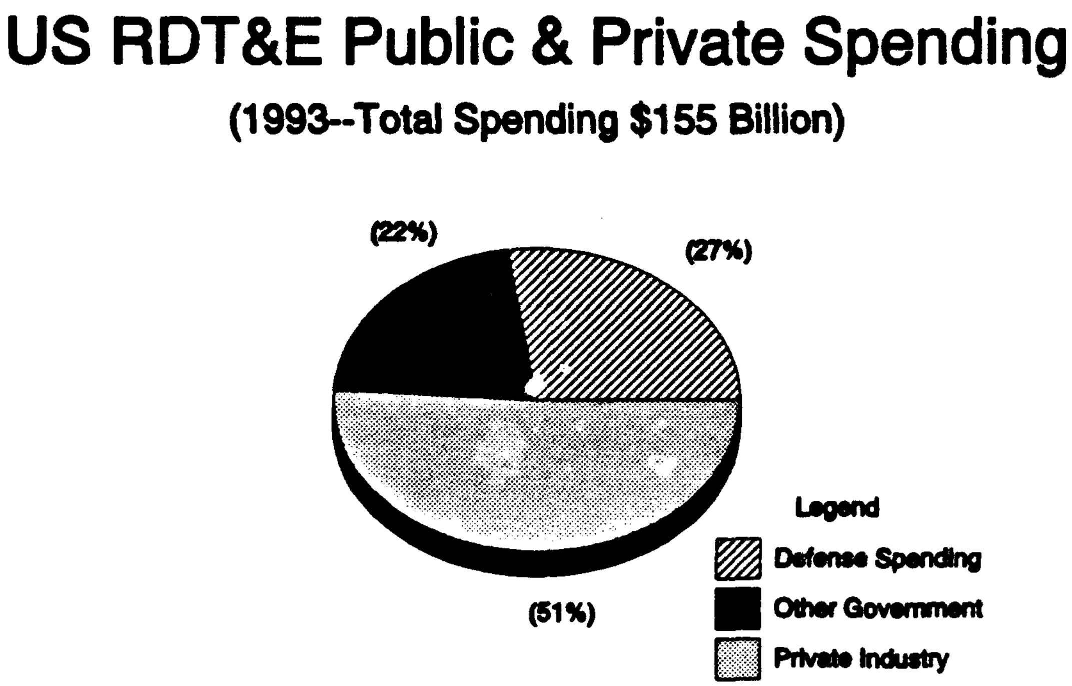

Figure 18: DoD Research, Development, Testing and Evaluation Budget.
SOURCE: Moteff, J.D., "Research and Development Funding: FY 1993," *CRS Issue Brief*, 13 Aug 92, p. 1.

technology advancement. Management and processes are contrary to the doctrine of ARPA. SEMATECH is part of the DoD because DARPA was the venue through which SEMATECH could obtain funding.

ARPA's mission is shifting from solely DoD interests to dual technology. Dual technology is designed to promote both civilian and military benefits. For ARPA to remain a part of the DoD is a question that will not be addressed here. According to Michele Higdon, SEMATECH is part of the DoD because the Semiconductor Industry

Association and Robert Noyce were able to "work the system." They knew how to win Congressional support. (Higdon)

VI. CONCLUSION

DoD is not responsible for funding industrial R&D. Instead, DoD is responsible for supporting requirements and specifications for systems and products that serve defense needs today and in the future. Further, DoD's responsibility is to select bids that best satisfy those needs. DoD may have to fund some R&D in conjunction with these products. Only in this manner will DoD receive the best product for its money and at the same time promote a free market by ensuring keen competition within industry. If the federal government decides to support commercial R&D, it should do so explicitly. Industrial R&D should not be disguised as a national security issue.

Several conclusions result from this thesis. First, SEMATECH is not responsible for the semiconductor industry's regaining market share. Second, SEMATECH is neither an effective nor efficient model for government-industry partnership. Finally, federal support for SEMATECH should cease.

A. SEMATECH IS NOT RESPONSIBLE FOR THE SEMICONDUCTOR INDUSTRY'S REGAINING MARKET SHARE.

The American semiconductor industry recently regained market share due to its specialization and innovations. U.S. chip makers are more interested in producing high-profit-margin products and purchasing low-profit-margin commodity-type-products overseas. This quest for specialized production requires innovation. The

demand for innovation to insure profitability is a tremendous incentive for U.S. semiconductor firms to invest in research and development. Innovative products are what created the market niches that spurned the recent industry turnaround. The semiconductor industry's recovery coincided with the SEMATECH's formation merely by chance. This is not to say that SEMATECH is a success or failure. Rather, it is to say that SEMATECH did not cause the U.S. semiconductor industry to regain market share. There is an inherent time factor in getting RDT&E products to market. After only five years, SEMATECH's R&D success cannot yet be determined. SEMATECH proponents could argue that SEMATECH concentrates more on the manufacturing process than product development, and that results from SEMATECH research in "process improvement" are already felt throughout the American semiconductor industry. (*SEMATECH Success*) If this were true, Harris Corporation would not have resigned from the consortium. (Blanc) The American semiconductor industry regained market share with superior, innovative products. These products were not influenced by SEMATECH.

B. SEMATECH IS NEITHER AN EFFECTIVE NOR EFFICIENT MODEL FOR GOVERNMENT-INDUSTRY PARTNERSHIP.

SEMATECH is not a model to be emulated. It is an improper model because SEMATECH is a self-perpetuating organization. SEMATECH is a stand-alone organization with impressive lobbying ability. SEMATECH has yet to declare

concrete objectives. SEMATECH is funded through the Department of Defense, but it seems to put little emphasis on defense.

Future government-industry partnerships cannot create independent associations. Future government-sponsored consortia must have definitive objectives that must be completed within a specified time. SEMATECH was said to be modeled after Japanese research and development consortia. If that were true, SEMATECH would have disbanded, and the billion dollar members would repay the $700 million loan. Instead, SEMATECH is more similar to Europe's JESSI, a permanent organization hoping for funding through this century.

Since SEMATECH's inception in 1987, it has not brought in a single new member. Worse, SEMATECH lost three founding members, one being the leading supplier of DoD semiconductors. SEMATECH seems content with its current membership and discourages additional membership by insisting that its initiation fees be cost-prohibitive for a new member to join.

Being a stand-alone organization, SEMATECH has gained strength over time, perpetuating its life. SEMATECH "success" is the epitome of industrial policy. But, it's difficult to determine the success of SEMATECH. The only thing that is assured is that SEMATECH will continue lobbying for it's annual grant.

A "SEMATECH-type" organization is not the proper model for future government-industry ventures. A better model would be the similar to the Japanese' VLSI model. Government-industry partnerships must have definite objectives that must be accomplished within a pre-determined period. To complete those objectives,

the partnership must rely on the existing infrastructure rather than forming a "stand-alone" organization. The policy of low-interest loans seems more appealing than government grants or subsidies.

C. FEDERAL SUPPORT FOR SEMATECH SHOULD CEASE.

To remain competitive in today's market, even the giants of the semiconductor industry have established numerous joint ventures with overseas partners or conglomerates. Spillovers from research and development in the semiconductor industry cannot be prevented. These spillovers of technology from SEMATECH member firms to foreign competitors are indirectly funded by American taxpayers. SEMATECH should not continue receiving government funds. SEMATECH has not invigorated chip making as it was initially designed, nor is SEMATECH the solution for government involvement with private industry. It is unlikely that SEMATECH will return the annual $100 million worth of benefit to the taxpaying public.

SEMATECH is an excellent example of good intentions and effort applied in a fundamentally flawed manner. Although it is difficult to determine who owns SEMATECH's current assets, if SEMATECH is to continue, it should be privately funded. The bottom line is that federal funding for SEMATECH should cease.

VII. RECOMMENDATIONS FOR FURTHER STUDY

Government-industry relations, industrial policy, consortia, the semiconductor industry are all very interesting topics. There are a number of areas for further study resulting from this thesis:

- If funds to SEMATECH cease, what happens to the organization?
- Does the Department of Defense have a responsibility to develop "dual-use" technology?
- Must the Department of Defense maintain the defense industrial base? If so, what is the best method to insure its preservation?
- What is the best model of government-industry partnerships?
- How can the government best determine the key industries to support?
- Does American research and development rely too heavily on federal subsidies?

LIST OF REFERENCES

Alcott, G., Technology Transfer Manager, Intel Corp. Telephone interview by author, 13 April 1993, Monterey, California.

Bernier, L. "JESSI Sets Technology, Applications Plans," *Electronic Engineering Times*, 19 October 1992, 4.

Blanc, A., Senior Engineering Manager, Harris Corp. Telephone interview by author, 18 July 1993, Monterey, California.

Blau, J.R. "Europe Stumbling in Semiconductor Race," *Research -- Technology Management*, March-April 1992, 3-4.

Brister, G. *Something About the Railroad Industry*. Monterey, California: Master's Thesis, Naval Postgraduate School, September 1993.

Carlton, J. & K. Pope. "Memory-Chips Supply is Hit by Japan Blast," *The Wall Street Journal*, 21 July 1993, B6.

Carpenter, J.D. *The U.S. Government Role in Foreign Trade -- What is the Best Approach? A Case Study of the U.S. Semiconductor Industry*. Monterey, California: Master's Thesis, Naval Postgraduate School, March 1990.

Cassell, J. and R. McCausland. "Worklife after SEMATECH Remains Iffy Proposition," *Electronic News*, v39 n1945 (11 January 1993): 1-2.

Cohen, T.R. and R.G. Noll. *The Technology Pork Barrel*. Washington, DC: The Brookings Institution, 1991.

Davey, M.E. "Managing Defense Department Technology Base Programs," *CRS Report for Congress*. Washington, DC: Congressional Research Service -- The Library of Congress, 21 April 1988.

Dertouzos, M.L., R.K. Lester, and R.M. Solow. *Made in America, Regaining the Productive Edge*. New York: Harper Perennial, 1990.

Economic Indicators. Prepared for the Joint Economic Committee by the council of Economic Advisors. Washington, DC: United States Government Printing Office, 1983.

Economic Indicators. Prepared for the Joint Economic Committee by the council of Economic Advisors. Washington, DC: United States Government Printing Office, 1993.

"Electronics Current Analysis." *Standard & Poor's Industry Surveys*, 10 June 1993.

Evan, W.M. and P. Oak. "R&D Consortia: A New U.S. Organizational Form." *Sloan Management Review*, Spring 1990, 37-45.

Flamm, K.S. *Targeting the Computer, Government Support and International Competition*. Washington, DC: The Brookings Institution, 1987.

Freidberg, A.L. "The End of Autonomy: The United States after Five Decades." Edited by R. Vernon and E.B. Kapstein. *Defense and Dependence in a Global Economy*. Washington, DC: Congressional Quarterly Inc., 1992.

Gates, W. "Federally Supported Commercial Technology Development: Solar Thermal Technologies 1970-1982." *Research Policy 17*, 1988, 27-42.

Gilder, G.F. *Microcosm, The Quantum Revolution in Economics and Technology*. New York: Simon and Schuster, 1989.

Gross, N. & R.D. Hof. "Why the Chip Industry Could Get Scorched," *Business Week*, 26 July 1993, 34.

"Harris Leaves SEMATECH," *San Jose Mercury News*, 6 Jan 1993, 3C.

Higdon, M., SEMATECH Communications Manager. Telephone interview by author, 15 July 1993, Monterey, California.

Katz, M.L. and J.A. Ordover. "R&D Cooperation and Competition," *Brookings Papers: Microeconomics 1990*, 137-203.

Lindsey, B. "Dram Scam," *Reason*, February 1992, 40-48.

Lineback, J.R. "JESSI Weighs Belt-Tightening," *Electronic News*, 29 March 1993, 2.

Lineback, J.R. and P. Dunn. "JESSI Seeks Extension; SEMATECH Eyes More Members," *Electronic News*, 16 November 1992, 7-8.

Moore, G.D. *Domestic Production and National Security -- Is There a Connection? A Case Study of SEMATECH Research Consortium*. Monterey, California: Master's Thesis, Naval Postgraduate School, June 1989.

Nelson, R.R., ed. *Government and Technical Progress, A Cross-Industry Analysis*. New York: Pergamon Press, 1982.

Nunno, R.M. "Defense R&D Restructuring," *CRS Issue Brief*. Washington, DC: Congressional Research Service -- The Library of Congress, 20 August 1992.

Okimoto, D.I., T. Sugano, and F.B. Weinstein. *Competitive Edge, The Semiconductor Industry in the U.S. and Japan*. Stanford, California: Stanford University Press, 1984.

Pankratz, J., of Texas Instruments/SEMATECH, Austin, Texas. Letter to R.M. Byron, Monterey, California, of 19 May 1993.

Rice, V. "SEMATECH: United We Stand?" *Electronic Business*, 1 May 1988, 8-10.

Rogers, T.J., CEO and President of Cypress Semiconductor Corporation, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology and Competitiveness, 23 July 1991.

Rogers, T.J., CEO and President of Cypress Semiconductor Corporation, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology, Environment, and Aviation, 25 March 1993.

Sanders, D., Technology Transfer Director, LSI Logic Corp. Telephone interview by author, 12 April 1993, Monterey, California.

SEMATECH Accomplishments. Austin, Texas: SEMATECH, Inc., December 1992.

"SEMATECH-Backed Firm Near Failure," *San Jose Mercury News*, 30 April 1993, 1G.

SEMATECH Milestones. A SEMATECH Memorandum detailing milestones from May 1986 to the third quarter 1989.

SEMATECH, Strategic Overview. Austin, Texas: SEMATECH, Inc., December 1991.

SEMATECH Success, 1992 Annual Report. Austin, Texas: SEMATECH, Inc., January 1993.

United States Congress. *The Benefits and Risks of Federal Funding for SEMATECH*. Washington, DC: Congressional Budget Office, September 1987.

United States General Accounting Office. *Federal Research, SEMATECH's Technological Progress and Proposed R&D Program*, GAO/RCED-92-223BR. Washington, DC: GAO Resources, Community, and Economic Development Division, July 1992.

Zieglar, J.N. "Defense and the Emergence of an Industry Structure." Edited by R. Vernon and E.B. Kapstein. *Defense and Dependence in a Global Economy*. Washington, DC: Congressional Quarterly Inc., 1992.

Zycher, B. "Defense," edited by D.R. Henderson. *The Fortune Encyclopedia of Economics*. New York: Warner Books Inc., 1993.

SELECTED BIBLIOGRAPHY

Alcott, G., Technology Transfer Manager, Intel Corp. Telephone interview by author, 13 April 1993, Monterey, California.

Barret, C. "Intel's Success Hasn't Taken Its Mind Off Washington," *Wall Street Journal*, 19 January 1993.

Bernier, L. "JESSI Sets Technology, Applications Plans," *Electronic Engineering Times*, 19 October 1992, 4.

Bhagwati, J. Review of *Rough Trade*, by L.D. Tyson. In *The New Republic* (31 May 1993): 35-40.

Blanc, A., Senior Engineering Manager, Harris Corp. Telephone interview by author, 16 July 1993, Monterey, California.

Blau, J.R. "Europe Stumbling in Semiconductor Race," *Research -- Technology Management*, March-April 1992, 3-4.

Brandt, R. "Chipping Away at Japan," *Business Week*, 7 December 1992, 120.

Brown, R. "How the Government Can Help," *Washington Technology*, 11 March 1993, 1.

Calhoun, H.C., IBM Corporation, Hopewell Junction, NY. Letter to R.M. Byron, 21 April 1993.

Carlton, J. & K. Pope. "Memory-Chips Supply is Hit by Japan Blast," *The Wall Street Journal*, 21 July 1993, B6.

Carpenter, J.D. *The U.S. Government Role in Foreign Trade -- What is the Best Approach? A Case Study of the U.S. Semiconductor Industry*. Monterey, California: Master's Thesis, Naval Postgraduate School, March 1990.

Carroll, J.D. "The Public Administration of Investment: Grappling with the Blind Men and the Elephant," *Public Administration Review*, May/June 1992, 223-237.

Cassell, J. and P. Dunn. "SEMATECH, AMD, HP Alight on 0.35-Micron," *Electronic News*, 25 January 1993.

Cassell, J. and R. McCausland. "Worklife after SEMATECH Remains Iffy Proposition," *Electronic News*, v39 n1945 (11 January 1993): 1-2.

Chapman, G. "Push Comes to Shove on Technology Policy," *Technology Review*, November/December 1992, 42-49.

Clark, D. "Chipmaking-Equipment Firms Surge: SEMATECH Helps U.S. Increase Share to 47%," *San Francisco Chronicle*, 9 April 1992, B1.

Clinton, W.J. "Technology for America's Economic Growth," speech of 1 March 1993.

Cohen, T.R. "A Model--But What Kind?" *Technology Review*, January 1992, 16-18.

Cohen, T.R. and R.G. Noll. *The Technology Pork Barrel*. Washington, DC: The Brookings Institution, 1991.

"Computers Current Analysis," *Standard & Poor's Industry Surveys*, 31 December 1992.

Corcoran, E. "Semiready: A Consortium Prepares for the Second Half of the Battle," *Scientific American*, November 1992.

"Creating a Roadmap for the U.S. Semiconductor Industry," *Solid State Technology*, April 1993.

Davey, M.E. "Managing Defense Department Technology Base Programs," *CRS Report for Congress*. Washington, DC: Congressional Research Service -- The Library of Congress, 21 April 1988.

Deagon, B. "SEMATECH's William Spencer: Building Support for Chip Consortium by Shifting Agenda," *Investor's Business Daily*, 10 November 1992, 1.

DeBare, I. "Back in the Chips: U.S. firms Went on the Offensive for Market Share," *The Sacramento Bee*, 11 January 1993.

Dertouzos, M.L., R.K. Lester, and R.M. Solow. *Made in America, Regaining the Productive Edge*. New York: Harper Perennial, 1990.

Drucker, P. "According to Peter Drucker," *Forbes ASAP*, 29 March 1993, 90-95.

Dunn, P. "SEMATECH Gets 'Green' Proposals," *Electronic News*, 12 April 1993, 12.

Dunn, P. "SEMATECH's Quality Management Theme Sparks a Big Response," *Electronic News*, 8 February 1993.

Dunn, P. "U.S. Semi Equipment Firms regain Share," *Electronic Buyers' News*, 13 April 1992, 3.

Economic Indicators. Prepared for the Joint Economic Committee by the council of Economic Advisors. Washington, DC: United States Government Printing Office, 1983.

Economic Indicators. Prepared for the Joint Economic Committee by the council of Economic Advisors. Washington, DC: United States Government Printing Office, 1993.

Egelhoff, W.G. "Great Strategy or Great Strategy Implementation--Two Ways of Competing in Global Markets," *Sloan Management Review*, Winter 1993, 37-50.

"Electronics Current Analysis." *Standard & Poor's Industry Surveys*, 10 June 1993.

Erickson, K. and A. Kanagal. "Partnering for Total Quality," *Quality*, September 1992, 17-20.

Evan, W.M. and P. Oak. "R&D Consortia: A New U.S. Organizational Form." *Sloan Management Review*, Spring 1990, 37-45.

Ferguson, T.W. "Intel's Success Hasn't Taken Its Mind Off Washington," *The Wall Street Journal*, 19 January 1993, A15 (W) and A15 (E).

Fisher, L.M. "Chip Consortium Achieves a Made-in-the-USA Feat," *The New York times*, 22 January 1993, C1.

Flamm, K.S. *Targeting the Computer, Government Support and International Competition*. Washington, DC: The Brookings Institution, 1987.

Forbes, M.S. Jr. "Fact and Comment," *Forbes*, 10 May 1993, 25-26.

Fried, L.I. "Industry Consortiums," *Management Review*, February 1989, 22-27.

Freidberg, A.L. "The End of Autonomy: The United States after Five Decades." Edited by R. Vernon and E.B. Kapstein. *Defense and Dependence in a Global Economy*. Washington, DC: Congressional Quarterly Inc., 1992.

Galvin, R.W., CEC of Motorola, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology and Competitiveness, 9 July 1993.

Gates, W. "Federally Supported Commercial Technology Development: Solar Thermal Technologies 1970-1982." *Research Policy 17*, 1988, 27-42.

Gates, W. "High-Tech Research Joint Ventures," Notes, 6 May 1988.

Ghemawat, P. "The Risk of Not Investing in a Recession," *Sloan Management Review*, Winter 1993, 51-58.

Gilder, G.F. "Chip Sense and Nonsense," *Wall Street Journal*, 2 April 1987.

Gilder, G.F. *Microcosm, The Quantum Revolution in Economics and Technology*. New York: Simon and Schuster, 1989.

Gilder, G.F. "Telecosm, the New Rule of Wireless," *Forbes ASAP*, 29 March 1993, 96-111.

Gross, N. & R.D. Hof. "Why the Chip Industry Could Get Scorched," *Business Week*, 26 July 1993, 34.

Hammer, K., CEO of ETI, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology and Competitiveness, 9 July 1993.

Harris, M.C. and G.E. Moore, ed. *Linking Trade and Technology Policies, An International Comparison of the Policies of Industrialized Nations*. Washington, DC: National Academy Press, 1992.

"Harris Leaves SEMATECH," *San Jose Mercury News*, 6 Jan 1993, 3C.

Harrison, B. "Winning Through Collaboration," *Technology Review*, January 1993, 26.

Henderson, D.R. *The Fortune Encyclopedia of Economics*. New York: Warner Books, Inc., 1993.

Higdon, M., SEMATECH Communications Manager. Telephone interview by author, 15 July 1993, Monterey, California.

"High-Technology Research Consortia: SEMATECH's Experience," Austin, Texas: SEMATECH, Inc., 1990.

Holding the Edge: Maintaining the Defense Technology Base. Washington, DC: Congress of the United States Office of Technology Assessment, 1989.

Johns, B. "U.S. Chip Makers Seek Policy to Broaden Cooperation," *Journal of Commerce*, 9 March 1993, 4A.

Johnson, W.A. *What Constitutes National Security in the Semiconductor Industry? A Look at the Competing Views Surrounding DoD's Support of Semiconductors*. Monterey, California: Master's Thesis, Naval Postgraduate School, December 1990.

Johnstone, B. "Reinventing Research," and "The Unquiet American," *Far Eastern Economic Review*, 24 May 1990, 68-70.

Katz, M.L. and J.A. Ordover. "R&D Cooperation and Competition," *Brookings Papers: Microeconomics 1990*, 137-203.

Kaufman, S. "IDT: Blueprint for a Silicon Valley Turnaround," *San Jose Mercury News*, 20 June 1993, 1E.

Krause, R. "SEMATECH Scores Big in Tech Plan," *Electronic News*, 1 March 1993, 12-13.

Ladendorf, K. "SEMATECH Celebrates Tiny Milestone in Microchip Race," *Austin American-Statesman*, 22 January 1993, A1.

Ladendorf, K. "SEMATECH Sees Good News in Equipment Sales Reports," *Austin American-Statesman*, 9 April 1992, B4.

Levander, M. "Is Government a Help or Hindrance in Reshaping the Economy?" *San Jose Mercury News*, 26 April 1993, D4.

Levander, M. "Jump-Starting an Industry," *San Jose Mercury News*, 26 April 1993, D1.

Lindsey, B. "Dram Scam," *Reason*, February 1992, 40-48.

Lineback, J.R. "JESSI Weighs Belt-Tightening," *Electronic News*, 29 March 1993, 2.

Lineback, J.R. "SEMATECH, JESSI Talks Progress Slowly," *Electronic News*, 12 April 1993, 12-13.

Lineback, J.R. and P. Dunn. "JESSI Seeks Extension; SEMATECH Eyes More Members," *Electronic News*, 16 November 1992, 7-8.

Markoff, J. "Rethinking the National Chip Policy: Foreign Pacts Raise Questions About an Industry's Need for U.S. Support," *The New York Times*, 14 July 1992, D1.

Markoff, J. "SEMATECH's New Mission is Defined," *The New York Times*, 5 October 1992, D1.

Markoff, J. "Shifting Role in Technology," *The New York Times*, 16 December 1992.

Marshall, E. "Industrial R&D Wins Political Favor," *Science*, 20 March 1992, 1500-1503.

Marshall, E. "U.S. Technology Strategy Emerges," *Science*, 5 April 1991, 20-24.

McCarroll, T. "Chips Ahoy!" *Time*, 23 November 1992, 62-63.

Melliar-Smith, M., of AT&T Microelectronics. Telephone interview by author, 23 April 1993, Monterey, California.

Mitchell, J.J. "American Way: Intel, AMD Bask in Failure," *San Jose Mercury News*, 21 October 1990, 1E.

Mivola, P. S. "More Like Them?" *The Brookings Review*, Spring 1991, 14-21.

Moore, G.D. *Domestic Production and National Security -- Is There a Connection? A Case Study of SEMATECH Research Consortium*. Monterey, California: Master's Thesis, Naval Postgraduate School, June 1989.

Moore, M. "U.S. Chip Makers Bounce Back." *PC Week*, 1 February 1993, 107-109.

Mowery, D.C. and D.J. Teece. "Japan's Growing Capabilities in Industrial Technology: Implications for U.S. Managers and Policymakers," *California Management Review*, Winter 1993, 9-34.

Murray, C.A. *Losing Ground, American Social Policy, 1950-1980*. New York: Basic Books, Inc., Publishers, 1984.

Neff, R., O. Port, and J.B. Levine. "The Costly Race Chip Makers Can't Afford to Lose," *Business Week*, 10 December 1990, 185-188.

Nelson, R.R. *High-Technology Policies, A Five-Nation Comparison*. Washington, DC: American Enterprise Institute for Public Policy Research, 1984.

Nelson, R.R., ed. *Government and Technical Progress, A Cross-Industry Analysis*. New York: Pergamon Press, 1982.

Noyce, R.N. "False Hopes and High-Tech Fiction," *Harvard Business Review*, January-February 1990, 31-34.

Nunno, R.M. "Defense R&D Restructuring," *CRS Issue Brief*. Washington, DC: Congressional Research Service -- The Library of Congress, 20 August 1992.

Okimoto, D.I., T. Sugano, and F.B. Weinstein. *Competitive Edge, The Semiconductor Industry in the U.S. and Japan*. Stanford, California: Stanford University Press, 1984.

Ouchi, W.G. *Information Sharing in High Technology Industry: A Survey*, SRC TR T86074. Research Triangle Park, North Carolina: Semiconductor Research Corporation, September 1986.

Ouchi, W.G. and M.K. Bolton. *The Logic of Joint Research and Development*, SRC TR T86102. Research Triangle Park, North Carolina: Semiconductor Research Corporation, October 1986.

Pankratz, J., of Texas Instruments/SEMATECH, Austin, Texas. Letter to R.M. Byron, Monterey, California, of 19 May 1993.

Parkinson, J.L., of Micron Technology, Inc., Boise, Idaho. Letter to R.M. Byron, Monterey, California, of 16 July 1993.

Peck, M.J. "Joint R&D: The Case of Microelectronics and Computer Technology Corporation," *Research Policy 15*, 1986, 219-231.

"Philips N.V.," *Multimedia Computing & Presentations*, 15 July 1992, S13-16.

Pitta, J. "The Realist," *Forbes*, 13 May 1991, 116.

Procassini, A.A. "Industry-at-Large," *Electronic News*, 28 September 1992.

Quinlan, T. "U.S., Japanese firms Join Up," *InfoWorld*, 20 July 1992, 28.

Ramstad, E. "SEMATECH Ready to Have a Major Impact on Market," *The San Antonio Light*, 21 June 1992.

Rhea, J. "New Direction for Industrial R&D Consortia," *Research -- Technology Management*, September-October 1991, 16-26.

Rice, V. "Chip Execs Cry for Help, Industry Panel Tells firms to Help Selves," *San Jose Mercury News*, 9 May 1990, 1F.

Rice, V. "Congressional Leaders Favor High-Tech Aid," *San Jose Mercury News*, 21 November 1989, 3C.

Rice, V. "The Decline of Chip Equipment Firms Industry's Fall to Hurt Chip Makers," *San Jose Mercury News*, 4 December 1989, 1D.

Rice, V. "SEMATECH: United We Stand?" *Electronic Business*, 1 May 1988, 8-10.

Rice, V. "SEMATECH's Activism Splits Industry," *San Jose Mercury News*, 21 May 1990, 1C.

Rice, V. "Valley Executives Fear U.S. Will stop Tech Research Aid," *San Jose Mercury News*, 29 April 1990, 1E.

Rice, V. and T. Schmitz. "Digging Our Own Grave, Silicon Valley May Be Trading Away Its Future in Deals with the Japanese," *San Jose Mercury News*, 10 December 1990, 1D.

Robertson, J. "Moore: Unify Tech Strategy," *Electronic News*, 27 July 1992, 1-3.

Robertson, J. "Sooey! Technology Pork Barrel," *Electronic News*, 28 September 1992, 9.

Robertson, J. "You Think You Got Troubles..." *Electronic News*, 23 November 1992, 9.

Robinson, B. "Big Changes in Tech Policy; Clinton Seeks shift from Defense to Commercial R&D," *Electronic Engineering Times*, 1 March 1993, 16-18.

Robinson, B. "Tech Breakthrough Heralds Jobs, Dollars," *San Jose Mercury News*, 20 May 1993, A1.

Rogers, T.J. "Landmark Messages from the Microcosm," *Harvard Business Review*, January-February 1990, 24-30.

Rogers, T.J. "The Road to High-Performance Computing: An Entrepreneur Endorses the Invisible Hand." *Cato Policy Report*, May/June 1993, 1, 10-12.

Rogers, T.J., CEO and President of Cypress Semiconductor Corporation, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology and Competitiveness, 23 July 1991.

Rogers, T.J., CEO and President of Cypress Semiconductor Corporation, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology, Environment, and Aviation, 25 March 1993.

Samuels, R.J. "Reinventing Security: Japan Since Meiji." Edited by R. Vernon and E.B. Kapstein. *Defense and Dependence in a Global Economy*. Washington, DC: Congressional Quarterly Inc., 1992.

Sanders, D., Technology Transfer Director, LSI Logic Corp. Telephone interview by author, 12 April 1993, Monterey, California.

Schmitz, T. and Rice, V. "U.S. Memories' Death Group Sounded Warning Siren," *San Jose Mercury News*, 14 January 1990, 1A.

Schneidawind, J. "Explosive Growth Ahead for Industry," *USA Today*, 22 January 1993, 1A.

SEMATECH Accomplishments. Austin, Texas: SEMATECH, Inc., December 1992.

"SEMATECH-Backed Firm Near Failure," *San Jose Mercury News*, 30 April 1993, 1G.

"SEMATECH Makes a Device 1/200th the Size of a Hair," *The Christian Science Monitor*, 25 January 1993.

SEMATECH Milestones. A SEMATECH Memorandum detailing milestones from May 1986 to the third quarter 1989.

"SEMATECH Reaches 0.35-micron Capability Using All-U.S. Equipment," *EDGE on & about AT&T*, 25 January 1993, 13-14.

SEMATECH, Strategic Overview. Austin, Texas: SEMATECH, Inc., December 1991.

SEMATECH Success, 1992 Annual Report. Austin, Texas: SEMATECH, Inc., January 1993.

"SEMATECH's New Role, Chip Venture Acts as Financier," *San Jose Mercury News*, 8 January 1990, 12D.

"SEMATECH's Spencer Says U.S. Must solve Own Problems and Stop Blaming Japanese," *International Trade Reporter*, 12 February 1992, 276.

Semiconductor Techno'.;y Workshop Conclusions. San Jose, California: Semiconductor Industry Association, :· .vember 1992.

Semiconductor Technology Workshop Working Group Reports. San Jose, California: Semiconductor Industry Association, November 1992.

Slater, M. "Computer makers Lead in High-End Processors: Economics of Systems Business Gives Computer Makers and Edge." *Microprocessor Report*, 12 February 1992, 3-4.

Southerland, D. "Consortium Sees Breakthrough in Chipping Away at the Chip," *Washington Post*, 22 January 1993.

Southerland, D. "Intel to Up Spending 33% on Plants, R&D," *Washington Post*, 19 December 1992, F1.

Spencer, W.J, CEO and President of SEMATECH, Testimony before the House Committee on Science, Space, and Technology, Subcommittee on Technology and Competitiveness, 9 July 1993.

Steele, L.W. "Needed: New Paradigms for R&D," *Research -- Technology Management*, July-August 1991, 13-21.

Stout, G. "Continuous Quality Improvements in the Electronics Industry," *Quality*, February 1993, 22-26.

"Telecommunications Current Analysis." *Standard & Poor's Industry Surveys*, 1 April 1993.

United States Congress. *The Benefits and Risks of Federal Funding for SEMATECH*. Washington, DC: Congressional Budget Office, September 1987.

United States Congress. *Using R&D Consortia for Commercial Innovation: SEMATECH, X-ray Lithography, and High-Resolution Systems*. Washington, DC: Congressional Budget Office, July 1990.

United States General Accounting Office. *Federal Research, SEMATECH's Technological Progress and Proposed R&D Program*, GAO/RCED-92-223BR. Washington, DC: GAO Resources, Community, and Economic Development Division, July 1992.

Wallace, R. "DRAM 'Dream Team:' IBM, Siemens, Toshiba Tie Up for 0.25-micron Tech," *Electronic Engineering Times*, 20 July 1992, 1-2.

Weber, J. "Chip Making Pioneer GCA Corp. Closes Factory," *Los Angeles Times*, 22 May 1993, D2.

Weber, J. "U.S. Milestone in Chip-Making is Reached," *Los Angeles Times*, 22 January 1993, D2.

Weber, J. "U.S. Sales of Chip Making Gear Improve," *The Los Angeles Times*, 9 April 1992, B1.

"When Industrial Policy Works," *Washington Post*, 29 August 1992, A18.

Wildstrom, S.H. "Curtains for a High-T^h Consortium?" *Business Week*, 14 October 1991, 57.

Wood, L. "U.S. Regains Lead in Chipmaking Equipment," *Chicago Tribune*, 14 March 1993.

Woolnough, R. "Mini-Environment Move: Europe Pushes for Wafer Fab Standards," *Electronic Engineering Times*, 8 March 1993, 36-38.

Zieglar, J.N. "Defense and the Emergence of an Industry Structure." Edited by R. Vernon and E.B. Kapstein. *Defense and Dependence in a Global Economy*. Washington, DC: Congressional Quarterly Inc., 1992.

Zycher, B. "Defense," edited by D.R. Henderson. *The Fortune Encyclopedia of Economics*. New York: Warner Books Inc., 1993.

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